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Towards a New Technological Paradigm Based on Industry 4.0: Opportunities and Challenges for Innovation Policies

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Abstract:

The analysis of the complex and fast changing technological processes which today are summarized in the term ‘Industry 4.0’ reveals that the industrial system is shifting towards a new technological paradigm (Perez, 2009; 2010), implying systemic transformations at micro, meso and macro levels of analysis (Geels, 2005). These radical transformations are deeply changing the way products, production processes and business models are conceived, questioning the traditional separation between manufacturing and services, and making it more and more important for firms to adopt a collaborative approach to innovation (Hagedoorn et al., 2000). This rapid technological advance implies the need for the socio-economic players to adopt new strategic and operational measures in order to prevent the loss of competitive advantage of national and regional innovation systems. The recent debate on industrial policies shows that a mission-oriented industrial policy approach (Mazzucato, 2014; European Commission, 2018) may provide interesting inspirational principles able to guide these transformations, since it places at the centre of its reasoning the key role of the public actor able to stimulate the strategic coordination between multiple socio-economic players at different levels (Mazzucato and Perez, 2014; Rodrik, 2004). According to this approach, Public-Private research Partnerships, are assumed to be effective vehicles of governance able to improve technological development, stimulating strong links between the relevant socio-economic players and thus increasing the national and regional systems’ overall innovative potential (Mazzucato, 2014; Rodrik, 2004; 2014; Robin and Schubert, 2013; Kristensen and Scherrer, 2016).

The aim of the present work is to understand how the strategic coordination between public and private players may be an opportunity for the definition of effective innovation policies in the context of the current socio-technical transition. In order to reach this purpose, a multilevel approach (Geels, 2005) is adopted, taking into account both the national and the regional levels of analysis.

A quantitative analysis is provided at national level in order to understand the relationship between a specific approach to innovation and technology policy, the overall innovation performance and the level of diffusion of cooperative innovation activities in a National Innovation System (Lundvall, 1988); moreover, it contributes to the existing literature on Public-Private research Partnerships (Hagedoorn et al., 2000) by testing the effectiveness of some main variables at industry and company level explaining the propensity of companies to get involved in formal cooperative innovation activities. This analysis is made taking into account data stemming from the 8th wave of the Community Innovation Survey, 2010-2012.

Moreover, the results of a field research conducted at regional level are presented, aiming at understanding the elements of an institutional/organizational framework which are able to positively influence technological local development. In this case, the analysis takes into account a Regional Innovation System (Cooke et al., 1997): the Autonomous Province of Trento. Data have been gathered through both primary sources, based on 57 semi-structured interviews to local institutions and firms, and secondary sources, based on relevant documents and reports. The major conclusion of the present work is that, given the systemic nature of this socio-technical transition, only a mission-oriented policy approach to innovation policy based on strategic Public-Private research Partnerships may be able to trigger the necessary cross-level synergies between the different socio-economic players involved, managing the important challenges lying behind these transformations.

Keywords: Industry 4.0; socio-technical transitions; mission-oriented policies; Public-Private research Partnerships; National Innovation System; Regional Innovation System

Contents

1. Chapter One: Introduction 12
1.1. Context 12
1.2. Main goal 13
1.3. Main conclusion 14
1.4. Innovative aspects 16
1.5. Structure of the Thesis 17
2. Chapter Two: Towards a new technological paradigm based on 'Industry 4.0', the need for a new approach to innovation policy 19
2.1. Industry 4.0: a new technological paradigm 20
2.1.1. Origins, concepts and meanings 20
2.1.2. Impact of 'Industry 4.0' in the economy and in business models 30
2.1.2.1. The role of digital platforms: some example applications 37
2.1.3. The policy approach of the main industrial powers 41
2.2. The need for a new approach in policy making during socio-technical transitions: the recent debate 44
2.2.1. Rationales of policy making in economic theory: from the market failure approach to the complexity theory 45
2.2.2. A mission-oriented approach to innovation policies in socio-technical transitions: some inspirational principles 53
2.3. Research questions, data and methodologies 56
2.3.1. The case of the Italian NIS: a quantitative analysis 58
2.3.1.1. Data and Methodologies 59
2.3.2. The case of Trento's RIS: a qualitative analysis 60
2.3.2.1. Data and Methodologies 61
3. Chapter Three: Italy's National Innovation System, Evidence from the Community Innovation Survey 2012 63
3.1. Italy's Innovation System 63
3.1.1. The institutional context 63
3.1.2. The approach to innovation and technology policies 65
3.1.3. The innovation performance: a comparison with some main European countries 67
3.1.3.1. The ICT sector 77
3.2. Evidence from the Community Innovation Survey 2010-2012 80
3.2.1. Literature review on the empirical studies on PPPs 80
3.2.2. The dataset 87
3.2.3. The model and the explanatory variables 97
3.2.4. Descriptive statistics 101

3.2.5. Results of the analyses 107
3.2.5.1. The propensity to cooperate with external partners 107
3.2.5.2. The propensity to cooperate with Italian and foreign Universities 113
3.3. Discussion and final remarks 119
3.3.1. The institutional setting, the approach to innovation policy and the overall innovation and technology performance in a NIS 119
3.3.2. Firms' propensity to develop PPPs 121
3.3.3. The lack of a strategic approach to innovation and technology policy: some final remarks 122
4. Chapter Four: The socio-technical transition towards 'Industry 4.0' in a Regional Innovation System, the case of the Autonomous Province of Trento 125
4.1. RISs: the empirical framework 125
4.1.1. Structure of the RIS and RIS types 125
4.2. The case of the Autonomous Province of Trento 134
4.2.1. Overview of the main performances and trends 134
4.2.2. The institutional framework 143
4.2.3. Research on the field 168
4.2.3.1. The sample and the questionnaire 168
4.2.3.2. Results of the interviews: Agrifood, Mechatronics and ICT 172
4.3. Discussion and final remarks 197
4.3.1. The analysis of the case study in the RIS framework 197
4.3.2. The approach of the firms and institutions to Industry 4.0 205
4.3.3. A top-down approach to innovation policy: a comparison with the national framework and some final remarks 210
5. Chapter Five: Conclusions 213
1. Basic steps of the research and main conclusion 213
2. Detailed conclusions 214
APPENDIX 221
REFERENCES 250

LIST OF TABLES

Table 1: Main definitions of 'Industry 4.0' 26
Table 2: KETs of 'Industry 4.0' 29
Table 3: Summary of the Innovation Index of the Italian country, relative to the European Union in 2010 ... 68
Table 4: R&D expenditure as percentage of GDP by sector of performance in some European countries 70
Table 5: GDP on R&D by source of funds in 2005 and in 2014 in some European countries 71
Table 6: Innovation indicators for some European countries in several years 73
Table 7: Human resources in science and technology and employment in high and medium-high tech sectors and KIS in some main European countries 75
Table 8: Top ten countries in terms of scientific publications 76
Table 9: ICT usage in the enterprises (percentages of enterprises) 78
Table 10: Percentages of firms employing ICT specialists and developing training courses for upgrading ICT skills 79
Table 11: Theoretical explanations of research partnerships 81
Table 12: Empirical contributions analyzing the determinants of firms' propensity to collaborate with external players 86
Table 13: Classification of the industries in terms of technological intensity in line with the OECD 89
Table 14: Distribution of the sample by sector 90
Table 15: Distribution of the sample by class of employees 90
Table 16: Goals considered highly relevant from innovative and non innovative firms in Italy, compared to other European countries involved in the CIS survey (percentages) 95
Table 17: Strategies considered highly relevant from innovative and non innovative firms in Italy, compared to other European countries involved in the CIS survey (percentages) 96
Table 18: Obstacles considered highly relevant from innovative and non-innovative firms in Italy, compared to other European countries involved in the CIS survey (percentages) 96
Table 19: Cooperation with other firms and institutions by country during 2010-2012 (percentages) 97
Table 20: List of dependent and independent variables used in the model 99
Table 21: Share of innovative firms by sector in 2010-2012 101
Table 22: Share of innovative firms by size in 2010-2012 101
Table 23: Share of innovative firms by sector and size in 2010-2012 101
Table 24: Share of innovative firms by sector, size and belonging to a group of firms in 2010-2012 102
Table 25: Main indicators of innovation by sector in 2010-2012 103
Table 26: Characteristics of innovative firms cooperating and not cooperating with other firms and institutions 104
Table 27: Characteristics of innovative firms cooperating and not cooperating with Universities 105
Table 28: Share of cooperative firms in 2010-2012 by type of partner and sector 106
Table 29: Share of firms cooperating with Universities (Italian and foreign) by sector in 2010-2012 107
Table 30: Coefficients of the logit model for cooperation with other firms and institutions 110
Table 31: Average marginal effects of the logit model for cooperation with other firms and institutions 111
Table 32: Propensity to cooperate with other firms and institutions (main results) 112
Table 33: Coefficients of the logit model for cooperation with Italian and foreign Universities 115
Table 34: Average marginal effects of the logit model for cooperation with Italian and foreign Universities 116
Table 35: Propensity to cooperate with Italian and foreign Universities (main results) 118
Table 36: Types of regions according to the system failures/deficiencies 131
Table 37: Organizational and institutional thickness/thinness of a RIS 132
Table 38: RISs types and regional industrial path development patterns 133
Table 39: Main socio-economic indicators in Trento, Italy and EU-15 134
Table 40: List of interviews by category, institution and department in Trento 143

Table 41: Main historical facts of Trento's Autonomy....147
Table 42: Main innovation projects in Trento....152
Table 43: Distribution of the sample of firms interviewed by NACE code....169
Table 44: List of the representatives of the firms interviewed by sector....171
Table 45: Share of the firms interviewed in the agrifood sector by NACE code, type, legal form, technological intensity and type of management....173
Table 46: Share of the firms interviewed in mechatronics by NACE code, type, legal form, technological intensity and type of management....178
Table 47: Distribution of the sample of firms interviewed in mechatronics by sector, size and belonging to technological hubs....179
Table 48: Share of the firms interviewed in the ICT sector by NACE code, type, legal form, technological intensity and type of management....187
Table 49: Summary of the results of the interviews....196
Table 50: Functional-structural analysis of the RIS and identification of the blocking mechanisms....203
Table 51: The approach to Industry 4.0 (level of adoption, advantages, obstacles and challenges) of the firms interviewed....208
Table 52: PPPs as effective tools of a mission-oriented innovation policy approach....209
Table 53: Propensity of firms to cooperate with Universities and public research centres: a comparison between the CIS (2010-2012) and the regional case study.....212
Table 54: Average marginal effects of the probit model without taking into account endogeneity....224
Table 55: Coefficients of the probit model taking into account endogeneity....225
Table 56: Average marginal effects of the probit model taking into account endogeneity....226
Table 57: Coefficients of the logit model for cooperation with other firms and institutions....229
Table 58: Average marginal effects of the logit model for cooperation with other firms and institutions....230
Table 59: Coefficients of the logit model for cooperation with group firms....230
Table 60: Average marginal effects of the logit model for cooperation with group firms....231
Table 61: Coefficients of the logit model for cooperation with clients and suppliers....232
Table 62: Average marginal effects of the logit model for cooperation with clients and suppliers....234
Table 63: Coefficients of the logit model for cooperation with competitors....235
Table 64: Average marginal effects of the logit model for cooperation with competitors....236
Table 65: Coefficients of the logit model for cooperation with Universities....237
Table 66: Average marginal effects for cooperation with Universities....238
Table 67: Coefficients of the logit model for cooperation with public research centres....239
Table 68: Average marginal effects of the logit model for cooperation with public research centres....240
Table 69: Coefficients of the logit model for cooperation with Italian Universities....241
Table 70: Average marginal effects for cooperation with Italian Universities....242
Table 71: Coefficients of the logit model for cooperation with foreign Universities....243
Table 72: Average marginal effects for cooperation with foreign Universities....245

LIST OF FIGURES

Figure 1: The Fourth Industrial Revolution 25
Figure 2: Design and principles of ‘Industry 4.0’ 26
Figure 3: The Circular Economy 36
Figure 4: A dynamic multi-level perspective on technological transitions 51
Figure 5: R&D expenditure as percentage of GDP in 2005 and in 2015 in some European countries 70
Figure 6: R&D expenditure in the manufacturing sector in 2013 in some European and extra-European countries 74
Figure 7: Innovative firms by type of innovation in some European countries in 2012 74
Figure 8: Scientific publications each 100 researchers 76
Figure 9: Share of the ICT sector in GDP in 2014 77
Figure 10: Distribution of the sample by size and sector 91
Figure 11: Distribution of the sample by group and headquarter of the group in 2012 92
Figure 12: Distribution of the sample by sector and type of operations implemented in 2010-2012 93
Figure 13: Percentage of firms with employees having a tertiary degree by sector in 2012 94
Figure 14: Distribution of the sample by level of internationalization in 2010-2012 by sector 94
Figure 15: Structural elements of a RIS 130
Figure 16: R&D expenditure on GDP at current prices in 2014 in Trento, Bolzano, Italy, North-East and EU 135
Figure 17: R&D expenditure on GDP at current prices by sector in 2014 in Trento, Bolzano, Italy, North-East and EU 136
Figure 18: School dropout rate for population between 18-24 years old in Trento, North East and Italy 137
Figure 19: Total R&D employees per 1000 inhabitants in Trento, Bolzano, North-East, Italy and EU 137
Figure 20: Graduated students in scientific and mathematical disciplines and participation to continuous training in Trento, North East, Italy and EU 138
Figure 21: Share of R&D employment in the private sector in Trento, Bolzano, North-East, Italy and EU 138
Figure 22: Patent applications to the European patent office per million of inhabitants by Italian region 139
Figure 23: Percentage of families having access to the Internet with broadband connection on total families in Trento, North-East and Italy 140
Figure 24: Percentage of firms with 10 or more employees having access to a broadband or mobile connection to the Internet in Trento, North-East and Italy 140
Figure 25: Firms’ propensity to export in Trento, North-East and Italy 141
Figure 26: Percentage of exports in the manufacturing sector on GDP at current prices in Trento, North-East and Italy 142
Figure 27: Distribution of the projects' revenues in FBK by unit 156
Figure 28: Distribution of the projects' revenues in FBK by counterpart 156
Figure 29: Research Lines conducted in ARES, FBK 159
Figure 30: Research Structure in ICT, FBK 160
Figure 31: Distribution of the projects' revenues in FBK by technological area 161
Figure 32: Distribution of the projects' revenues in FBK by counterpart 161
Figure 33: “TreC” the Public-Private Partnership for the citizens’ digital medical record 164
Figure 34: Competences of the Mechatronics Hub for the 5 goals of manufacturing challenge in Horizon 2020 167
Figure 35: Polo Meccatronica Master plan 167
Figure 36: Distribution of the sample of firms interviewed by sector 168
Figure 37: Distribution of the sample of firms interviewed by technological intensity 169
Figure 38: Distribution of the sample of firms interviewed by class of employees 170
Figure 39: Distribution of the sample of firms interviewed by type of enterprise 170

Figure 40: Distribution of the sample of firms interviewed by societal form 171
Figure 41: The role of Simulation Bases Engineering Science for ‘Industry 4.0’ KETs...............................192
Figure 42: The shift from the ‘Industrial’ to the ‘Digital’ era..194
Figure 43: Main business areas of Dedagroup...194
Figure 44: Trento’s innovation system 202
Figure 45: Path diagram of the GSEM with latent variables..228

1. Chapter One: Introduction

1.1. Context

During the last decades, technological evolution has proceeded at such a high speed that, according to academics, scholars and policy makers, we have entered the “fourth industrial revolution” (Schwab, 2016; World Economic Forum, 2016; Arthur, 2011). Cyber-Physical Systems have been hailed as the linchpin of this technological wave, making it possible for the physical world to be completely integrated into the ‘cyber’ world (Acatech, 2011; Lee, 2015; Hermann et al., 2015). ‘Internet of Things and Services’, ‘Big Data Analytics’, ‘Cloud Computing’ ‘Autonomous Robots’, ‘Augmented Reality’, ‘Additive Manufacturing’, ‘Cybersecurity’ are the Key Enabling Technologies (KETs) of this new technological age, leading to radical changes in the economy, businesses, society and individual lives; the continuous flow of goods, people and information is progressively transforming territorial agglomerations and cities with the global connectivity space increasing exponentially (Acatech, 2015; MGI, 2013; Lombardi, 2017; Capone and Lazzeretti, 2016; Lazzeretti et al., 2017).

In this broad scenario, the industrial system is going through deep changes in the way products, production processes and business models are conceived (Acatech, 2011; 2013; GTAI, 2015; Deloitte, 2014; McKinsey, 2016; Roland Berger, 2011; 2014; 2015; World Economic Forum, 2015; Osservatorio Smart Manufacturing, 2015). The border between manufacturing and services is progressively vanishing, giving the way to a holistic view of the industry, in which manufacturing and services are deeply and synergistically related (McKinsey, 2012; Crandall and Crandall, 2013; Lombardi, 2017). Products are becoming increasingly *multi-technology*, resulting from the integration of a wide range of different knowledge domains, from mechanics, information technology and electronics to physics, mathematics and chemistry. In an increasingly hypercompetitive environment, digital ecosystems make it possible for firms and organizations to experience a higher flexibility, scalability and efficiency in a variety of contexts, from manufacturing, logistic and energy services to farming and health care (Acatech, 2015; Deloitte, 2014; Lombardi, 2017).

The exponential growth in technological progress is producing such a deep impact on the economy and businesses that many academics agree on the need for new ‘lenses of analysis’ in economic and business theory (Schwab, 2016; Lombardi, 2017). The diffusion of digital information technologies is producing a number of counterintuitive phenomenon which still remain poorly understood: the so-called ‘productivity paradox’, the relatively low increase in productivity rates of developed economies, despite the exponential growth in digital technologies of recent years (Schwab, 2016); the ongoing anomaly related to the ‘Internet of Things’ for which large segments of economic life are characterized by increasing productivity and lower, almost zero, marginal costs (Rifkin, 2014; Schwab, 2016); the downturn after the ‘Great Recession’ in the global economic growth rate, shifting from 5% to 3-3.5%, with no signs of recovery; the rising income inequality (Mazzucato and Jacobs, 2016) and the stagnation in living standards of many developed countries which have been the cradle of the digital revolution.

Following the financial crisis of 2007 and the economic recession of Western economies, there has been a revival in the debate around the need for effective industrial policies able to manage these challenges and to reach 'smart, sustainable and inclusive growth' (Forum, 2015; European Commission, 2010). Many academics agree on the need to abandon the old ideological opposition between the State 'picking the winners' and the market able to 'self regulate', suggesting a new approach to policy making which properly addresses the key role of the public actor in driving economic growth and job creation, in a constant strategic dialogue with the private sector (Forum, 2015; Rodrik, 2004; Warwick, 2013; Mazzucato, 2014; Mazzucato and Perez, 2014; Mazzucato and Jacobs, 2016; Frenken, 2017).

In the current policy debate, strategic Public-Private research Partnerships[1] (PPPs), once limited to instruments for public infrastructural development, are more and more recognized as effective tools of innovation policy, able to improve technological development both at national and regional levels (Link, 2006; Mazzucato, 2014; Rodrik, 2004; 2014; Robin and Schubert, 2013; Kristensen and Scherrer, 2016; Fogelberg and Thorpenberg, 2012; OECD, 2016). This trend is witnessed by the recent proliferation of strategic programmes developed by the main worldwide industrial powers, as "Advanced Manufacturing" in the United States (U.S.),"Platforme Industrie 4.0" in Germany, "Smart Factories" in the Netherlands, "Usine du Futur" in France, "Catapult" in the United Kingdom (UK), "Piano Nazionale Industria 4.0" in Italy (PCAST, 2011; 2014; Acatech, 2013; NFI, 2016; TSB, 2012; 2014; X Commissione Permanente, 2016) aimed at stimulating the optimal use of the new technologies for all the industrial sectors and managing the transition towards high-value digitized products and processes (Acatech, 2013; PCAST, 2014; European Commission, 2015).

1.2. Main goal

In the context of the urgent need to define new rationales of policy making able to manage these challenges, the aim of the present Thesis is to understand how the strategic coordination between public and private players may be an opportunity for the definition of effective innovation policies able to successfully guide the socio-technical transition towards a new technological paradigm (Perez, 2010), the so-called 'Industry 4.0'. In order to deal with this complex research objective, a multi-level perspective is adopted (Geels, 2005), involving the micro, the meso and the macro levels of analysis and using both quantitative and qualitative methodologies.

In the first step of the research, a quantitative analysis is performed in order to explore the relationship between a specific approach to innovation policy and the level of innovation and technology performance in a National Innovation System (NIS), taking into account the case of the Italian country.

[1] In the present work, PPPs are defined according to OECD (2016), as "legal relationships or agreements over fixed-term/indefinite period of time, linking public and private players - industry, universities, public research/technology institutions, entrepreneurs, etc. - where both sides interact in the decision making process, and co-invest scarce resources, such as money, personnel, facility, and information in order to achieve specific joint objectives in research and innovation" (OECD, 2016, p.1). These include: R&D projects, training and mobility programmes, large scale collaborative R&D projects, centres of excellence, research and technology institutes, collaborative research centres for applied research, collaborative R&D consortia, technology/competence centres (cluster or technology focused).

Specifically, the analysis focuses on the level of diffusion of formal R&D agreements between public and private players and on the factors explaining firms' propensity to get involved in these PPPs. For this first analysis, I draw on the literature on cooperative innovation (Hagedoorn et al., 2000; Belderbos et al. 2004, Veugelers and Cassiman, 2005; Fritsch and Lukas, 2001; Bayona et al. 2001; Miotti and Sachwald, 2003; Mowery et al., 1998; Caloghirou et al. 2003; Fontana et al. 2006; Lööf and Brostrom, 2008; Schartinger et al. 2002; Robin and Schubert, 2013; Schøtt and Jensen, 2016), using data on the Italian innovative companies stemming from the 8th wave of the Community Innovation Survey (CIS8, 2010-2012). Some conclusions are drawn on the relationship between the Italian approach to innovation policies and the level of innovativeness and cooperativeness with other players, specifically with Universities, of the Italian firms; moreover, some reflections are provided on whether a prevalently bottom-up/market-driven approach to innovation policy making is sufficient to stimulate the overall innovative performance and level of diffusion of collaborative innovation projects in a NIS.

In order to better understand whether a more top-down/institutional-led approach to innovation policy stimulates a system's technological development and innovation performance, the second step of the research performs a qualitative analysis of an institutional-led Regional Innovation System (RIS) which has proven to be managing successfully the 'Industry 4.0' transition (RIM, 2016): the Autonomous Province of Trento[2]. Drawing on the literature on RISs (Cooke et al., 1997; Doloreux, 2002; Doloreux and Dionne, 2008; Isaksen and Trippl, 2014; Tödtling and Trippl, 2005; Tödtling and Trippl, 2013; Asheim and Coenen, 2006; Bruneel et al., 2010; Hassink, 2002; Fritsch, 2002; Tödtling and Kaufmann, 1999; Autio, 1998; Trippl, 2006; Trippl et al., 2015a; Trippl et al. 2015b; Etzkowitz and Leydesdorff, 2000; Leydesdorff, 2000), I analyze the elements of an institutional/organizational framework which are able to positively influence technological development at the local level. Specifically, the analysis focuses on the following aspects: (i) the structural elements of the RIS (knowledge generation and diffusion subsystem, the regional policy subsystem, the local interactions between the relevant dimensions and the socio-institutional factors) favouring/blocking technological development at the local level; (ii) the approach of local firms and institutions to 'Industry 4.0' and the role of PPPs in supporting local technological development; (iii) whether the adoption of a top-down approach to innovation policy is sufficient to trigger the cross-level synergies between the players of the RIS, thus favouring the socio-technical transition towards 'Industry 4.0'. For this analysis the methodologies adopted are qualitative, based on the case study approach (Eisenhardt, 1989; Yin, 1994). Data are collected through both primary and secondary sources.

1.3. Main conclusion

The rich literature on the topic analyzed and the empirical analyses lead to some main conclusions. The analysis of the disruptive technological processes summarized in the term 'Industry 4.0' has shown that the industrial system is shifting towards a new technological paradigm (Perez, 2010), characterized by the

[2] Trentino Alto-Adige is formed by two autonomous provinces, the Autonomous Province of Trento and the Autonomous Province of Bolzano; due to their different jurisdictions, they may be considered as separate regions.

progressive integration between the physical and the virtual space: Cyber-Physical Systems are increasingly embedding the cyber capabilities in the physical world, amplifying exponentially the global connected space and leading to radical new ways of conceiving products, production processes and business models.

In order to guide this socio-technical transition, characterized by deep techno-scientific, techno-productive and techno-economic discontinuities, the mainstream approach to policy making, based on the market and system-failure theories, does not seem to provide effective guidance. In fact, these theories, based on the assumption that the market, or the system, is able to spontaneously achieve the equilibrium, except in particular cases in which the market or the system fails, may be useful in steady state scenarios, that is when the economic system is positioned in an existing technological trajectory; however, this may not be the case during technological revolutions, characterized by deep transformation processes at micro, meso and macro levels of analysis, requiring a constant and systematic coordination process between both public and private players at different levels (Mazzucato, 2014; Geels, 2002; 2004; 2005; Perez, 2001; 2010).

In this technological framework, a 'mission-oriented' approach to policy making may provide some interesting inspirational principles since it places at the centre of its reasoning the key role of the public actor able to stimulate the strategic coordination between multiple socio-economic players at different levels; this approach recognizes to the public authority not just the role of 'fixing' markets, but the potential to shape and create new markets, through the definition of problem-specific societal challenges, managed through strategic PPPs; this approach is able to create the potential for greater spillovers than a sectoral approach, stimulating the cross-level synergies between the socio-economic players, and thus facilitating socio-technical transitions (Mazzucato, 2014; Mazzucato and Perez, 2014; Perez, 2010; Geels, 2005).

This main conclusion is supported by both the quantitative analysis performed at national level and by the qualitative analysis performed at regional level.

The analysis at national level shows that a prevalently bottom-up approach to innovation policy, based on the substantial lack of a strategic action of the public actor in the field of innovation is associated to a relatively weak innovation and technology performance of the overall system; moreover, the firms reveal to have a relatively low propensity to develop formal R&D agreements, which are prevalently driven by factors at industry and firm levels. The analysis at regional level suggests that, despite the presence of specific geographical and territorial constrains hindering local development, the strong institutional setting of the regional system, presenting some elements of a 'mission-oriented' approach to policy making, shows to be an effective driver in the current technological scenario. In fact, this approach is able to activate bottom-up solutions through the network of local institutions and innovation agencies which are able to raise the knowledge creation, the technological development and the overall innovative potential of the system. A crucial role in this direction is played by the local network of multi-scalar organizations which continuously interact with extra-national sources of knowledge, triggering local path-renewal processes.

Moreover, the condition for this approach to policy making to be effective is the system's adequate level of absorptive capacity, which usually takes time to adapt during socio-technical transitions (Geels, 2002; Perez, 2010). In order to raise the system's level of absorptive capacity, the local strategic PPPs reveal to be effective instruments of policy making able to translate locally the multiple knowledge inputs of this multi-scalar framework. This mixed-approach to policy making, based on both top-down and bottom-up measures favours the socio-technical shift towards ‘Industry 4.0’, as confirmed also by the recent report of the Regional Innovation Monitor (RIM, 2016), which indicates Trento as one of the Italian regions which is managing successfully the transition.

These final considerations lead to a further implication of the present study, opening up to a new line of research to be developed. Overall, both the analyses performed at national and regional levels suggest the need to adopt new lenses of analysis for the study of innovation processes; the theoretical concepts of national and regional innovation systems, usually adopted as categories in the innovation literature, must evolve in order to deal with the current technological scenario. In fact, the integration between the ‘physical’ and the ‘virtual’ dimensions is widening exponentially the global connectivity space, thus questioning the significance of the ‘territorial’ dimensions of innovation systems. These categories, which have represented the traditional framework for the analysis of innovation processes must be revised in order to take into account the fundamental role played by the sub-system of global networks, research centres, public organizations and global players which act as catalyzing agents for local development, through the constant combination of the ‘global’ and the ‘local’ dimensions.

1.4. Innovative aspects

First of all, the present Thesis is one of the first scientific contributions which critically reviews the literature available till now on ‘Industry 4.0’, analyzing the main impact of this new technological paradigm (Perez, 2010) in the economy and in business models and addressing the need for a new approach to policy making (Rodrik, 2004; 2014; Mazzucato, 2014; Mazzucato and Perez, 2014; Forum, 2015).

The quantitative analysis contributes to the literature on NISs (Lundvall, 1988) by providing an in-depth analysis of the Italian NIS, highlighting the need for the Italian country to seriously rethink its approach to innovation and technology policies, in order to fill the gap in terms of innovative and technology performance with the other European countries. Moreover it contributes to the literature on collaborative innovation agreements (Hagedoorn et al., 2000) by analysing the factors influencing firms’ propensity to develop formal R&D agreements with other firms and institutions, taking into account for the first time data on innovation activities stemming from the 8^{th} wave of the CIS for the Italian country.

The qualitative analysis, realized through data gathered personally on the field, contributes to the literature on RISs by: (i) analysing the main blocking mechanisms hindering local development, through a functional-structural framework; (ii) identifying a possible path development trajectory in an institutional-driven RIS type; (iii) providing an in-depth analysis of the local firms and institutions’ approach to ‘Industry 4.0’, focusing in particular on the advantages, obstacles and main challenges firms are facing in the adoption of the ‘Industry 4.0’ KETs; (iv) analyzing the role of local strategic PPPs in favouring the adoption of the ‘Industry 4.0’ KETs; (v) testing the importance of the factors at firm and industry level driving the local firms’ propensity to get involved in PPPs with other firms and institutions, specifically with Universities and comparing them with the results obtained at national level; (v) highlighting a new trajectory in innovation studies on RISs, which goes beyond the geographical boundaries of innovation systems, rethinking them in the context of the increasingly globally connected space, the 'Physical-digital Multiverse' (Lombardi 2017), where multi-scalar organizations act as catalyzing agents.

1.5. Structure of the Thesis

The present Thesis is structured in three main chapters.

Chapter Two contains the building blocks of the literature taken into account for this research: in the first building block, the literature on 'Industry 4.0' is critically reviewed on the basis of some of the most significant contributions on the topic, detailing the origins and meanings, the impact in terms of economy and business models and the policy approaches adopted by the major industrial powers; the second building block provides a review of the main approaches to policy making in economic theory, focusing on the limitations of the mainstream theory in the current phase of socio-technical transition and presenting the main lines of reasoning of the 'mission-oriented' approach to policy making. Finally the last section defines the research questions addressed and the data and methodologies adopted.

Chapter Three contains the quantitative analysis on Italy's NIS, using the CIS 2010-2012 file of anonymized micro-data. The first section analyzes Italy's innovation system (Virgillito and Romano, 2014), describing the institutional context and the approach to innovation and technology policies adopted (Lucchese et al, 2016) and analyzing Italy's innovation and technology performance and level of diffusion of cooperative innovation projects in comparison to some main European countries. The second section contains the empirical analysis on CIS data. First of all, it provides an overview of the main empirical contributions on PPPs (Hagedoorn et al., 2000; Belderbos et al. 2004, Veugelers and Cassiman, 2005; Fritsch and Lukas, 2001; Bayona et al. 2001, Miotti and Sachwald, 2003; Mowery et al. 1998; Caloghirou et al. 2003; Fontana et al. 2006, Lööf and Brostrom, 2008; Evangelista, 2007; Schartinger et al. 2002; Segarra-Blasco and Arauzo-Carod, 2008; Robin and Schubert, 2013; Schøtt and Jensen, 2016); second, it provides the descriptive statistics and the models adopted for the empirical analysis, estimating the propensity of Italian firms to cooperate with external partners and, specifically, with Universities.

Chapter Four presents the qualitative case study on Trento. The first section is a brief overview of the literature on RISs from an empirical point of view (Cooke et al., 1997; Doloreux, 2002; Doloreux and Dionne, 2008; Hassink, 2002; Fritsch, 2002; Tödtling and Kaufmann, 1999; Autio, 1998) and on the 'triple helix' model (Etzkowitz and Leydesdorff, 2000; Leydesdorff, 2000; Bruneel et al., 2010) focusing on the structure and on the relationship between different regional types and path development trajectories (Isaksen and Trippl, 2014; Tödtling and Trippl, 2005; Tödtling and Trippl, 2013; Asheim and Coenen, 2006; Trippl, 2006; Trippl et al., 2015a; Trippl et al. 2015b); the second section is dedicated at deeply analyzing the case of Trento, reviewing the main performances and trends, the institutional framework and the results of the interviews to the enterprises. The final section discusses the main results in light of the literature on RISs. Finally, a concluding Chapter outlines the main implications of this work and the possible future lines of research.

2. Chapter Two: Towards a new technological paradigm based on 'Industry 4.0', the need for a new approach to innovation policy

Introduction

In recent years, the term 'Industry 4.0' has increasingly attracted the interest of academics, business managers and policy makers, due to the great potential lying in it in terms of economic, business, political, social and cultural impact. In fact, the pervasiveness of the 'Internet of Things and Services' in our lives is producing such profound changes, that a "fourth industrial revolution" is unfolding, based on the capability of networking wirelessly resources, information, objects and people; the progressive convergence of the physical into the virtual world (cyberspace) is changing deeply the way economic and business processes are conceived (Acatech, 2013; European Parliament, 2015). In the context of this paradigmatic shift (Perez, 2010; Schwab, 2016; Lombardi, 2017), it has become more and more urgent for governments to define a proper strategic 'socio-political choice' able to effectively guide these transformations and fully exploit the potential inherent in this revolution (Perez, 2013; Mazzucato and Perez, 2014).

The need for effective industrial policies has been at the centre of the debate among academics and policy makers since the Great Recession following the financial crisis of 2007, which has revealed the inadequacy of a 'laissez affaire' approach to policy making in assuring the stability of the economic system, implying a deep rethinking of the relationship between the State and the market (European Commission, 2010; 2014; Forum, 2015; Bianchi and Labory, 2011). Today, academics and policy makers agree on the need to abandon the old ideological opposition between the State 'picking the winners' and the market able to 'self regulate': a 'mission-oriented' approach to policy making is emerging, based on the synergic cooperation between the public and private players. According to this emerging approach, the public actor defines strategic lines of action laying the foundations for the private sector to radically innovate (Mazzucato, 2014; Rodrik, 2004; 2014; Mazzucato and Jacobs, 2016).

The present Chapter critically reviews the literature on 'Industry 4.0', on the basis of the most relevant contributions on the topic, and discusses the need for a new approach to policy making in socio-technical transitions. In light of the literature review, the research questions, data and methodologies are specified. The first section (2.1) provides a literature review on the main focal points of the debate around 'Industry 4.0', focusing on the origins and development of the concept and on the main KETs, the impact in terms of economy and business models, and the policy approaches adopted by the major industrial powers. The second section (2.2) summarizes the recent debate on policy making; first, it provides an overview of the main economic theories on public intervention, from the neoclassical theory to the systems of innovation approach and complexity theory; second, it discusses the need for a new theoretical approach in policy making in socio-technical transitions according to recent contributions (Geels, 2002; 2004; 2005; Mazzucato, 2014; Mazzucato and Perez, 2014; Rodrik, 2004; 2014; Forum, 2015). Finally, on the basis of the theoretical contributions analyzed, the third section (2.3) specifies the research questions addressed in this Thesis.

2.1. Industry 4.0: a new technological paradigm

2.1.1. Origins, concepts and meanings

The origins and development of the concept

The concept of ‘Industry 4.0’ traces its origin back to the 2006 High Tech Strategy of the German government[3] (BMBF, 2006). In November 2011, ‘Industry 4.0’ is explicitly indicated as a strategic initiative of the High-Tech Strategy 2020, launched in January 2011 by the Communication Promoters Group of the Industry-Science Research Alliance (FU). Its initial implementation recommendations were elaborated by the Industrie 4.0 Working Group between January and October 2012[4]. This work provides a starting point for a final report, which was published in 2013, named “Recommendations for implementing the strategic initiative INDUSTRIE 4.0, Final report of the Industrie 4.0”, highlighting Germany’s global competitive advantage in the manufacturing industry, thanks to its strong machinery and plant manufacturing industry, its high level of IT competences and its know-how in embedded systems and automation engineering, placing the country in a leading position in the area of Industry 4.0[5].

Starting from 2011, a similar industrial strategy has been pursued by the American government; in the U.S., President’s Council of Advisors on Science and Technology (PCAST) and President’s Innovation and Technology Advisory Committee issued in June 2011 a report to the President titled “Ensuring American Leadership in Advanced Manufacturing”, outlining the need to identify a strategy and specific recommendations for uplifting the leadership in “advanced manufacturing” (PCAST, 2014). Although in a first stage ‘Industry 4.0’ has been prevalently object of debate among German and American practitioners and academics (BMBF, 2006; Acatech, 2013; Hermann et al., 2015; PCAST, 2011; PCAST, 2014), in recent years, initiatives around ‘Industry 4.0’ and ‘advanced manufacturing’ have been developed throughout the major industrial powers. Today, it has become one of the priorities of the present policy agendas and it is identified as the main challenge to be faced in the next century (Roland Berger, 2014; Deloitte, 2014; European Parliament, 2016; Schwab, 2016).

[3] In this document, technological innovation is suggested as the way to secure Germany’s strong competitive advantage and six main cutting-edge priority fields are identified: health research, security technologies, energy technologies, optical technologies, information and communication and nanotechnologies.

[4] They were realized with the coordination of Acatech - National Academy of Science and Engineering, chaired by Dr Siegfried Dais, Deputy Chairman of the Board of Management of Robert-Bosch GmbH, and Prof. Henning Kagermann, President of Acatech, and presented as a report to the government at the Industry-Science Research Alliance’s Implementation Forum held at the Produktionstechnisches Zentrum Berlin, the 2nd October 2012.

[5] The report summarizes the vision and provides some example applications; moreover, it explains the main points of the government strategic initiative: “Platform Industrie 4.0”, led by the Ministries of Economy and Research; this platform brings together representatives from business, science and trade unions, with the aim to develop Germany’s international position in industrial manufacturing, promoting digital structural change and developing a consistent overall understanding of Industry 4.0 among all its members. In April 2015, the Platforme issued a report, in which Industry 4.0 is indicated as one of the crucial aspects of our economic and social life, to be explored in the nearest future; a research roadmap for a long term political strategy until 2030 is presented (VDE, 2015).

Definitions and meanings

In German Trade and Invest (GTAI) (2015), a first definition of Industry 4.0 is provided:

"A paradigm shift...made possible by technological advances which constitute a reversal of conventional production process logic. Simply put, this means that industrial production machinery no longer simply "processes" the product, but that the product communicates with the machinery to tells it exactly what to do" (GTAI, 2015, p. 7).

The first three industrial revolutions (Figure 1) have been the result of, respectively, mechanisation, electricity and IT; the first industrial revolution is symbolically represented by the mechanical loom, invented in 1784, which signed the beginning of mechanical production driven by water and steam power, developing throughout the 19th century; the second industrial revolution, exemplified by the first conveyor belt, Cincinnati slaughtered house in 1870, gave an important contribution to the development of mass production achieved thanks to the division of labour and electrical energy; the third industrial revolution, characterized by the first Programmable Logic Controller (PLC), making it possible the integration between electronics and Information Technologies (IT) in order to stimulate further automated production.

Today, the integration of the 'Internet of Things' and 'Internet of Services' into the manufacturing environment is producing disruptive changes so that many academics and practitioners refer to them as the beginning of a 'fourth industrial revolution'; whether the present shift is simply an extension of the third IT Revolution or a proper paradigmatic shift, is still matter of debate. Schwab (2016) refers to it as an effective paradigm shift for three main reasons: velocity, in the sense that the current transformations are evolving at an exponential rather than linear pace, as a result of a "multifaceted, deeply interconnected world" (Schwab, 2016, p. 3); breadth and depth, since the combination of multiple technologies implies paradigm shifts in the economy, business, society and individuals, changing not only the way things are done, but our deep identity; systems impact, involving the transformation of entire systems within and throughout countries, companies, industries and society as a whole[6].

As the first industrial revolution was signed by the first mechanical loom, the second and the third respectively by the Cincinnati slaughterhouse and the first PLC, this current paradigm shift is driven by the so called Cyber-Physical Systems (CPS). Acatech (2011) defines CPS as:

"Systems with embedded software (as part of devices, buildings, means of transport, transport routes, production systems, medical processes, logistic processes, coordination processes and management processes), which: directly record physical data using sensors and affect physical processes using actuators;

[6] The deep interconnection between the physical and the digital dimensions is producing what Arthur (2011) calls a "second economy (...) that's vast, automatic, and invisible - thereby bringing the biggest change since the Industrial Revolution" (Arthur, 2011, p.3). An illustrative example of the creation capacity of the virtual economy is provided by Arthur (2011), who compares the 'second economy' to the root system for aspen trees. "If I were to look for adjectives to describe this second economy, I'd say it is vast, silent, connected, unseen, and autonomous (meaning that human beings may design it but are not directly involved in running it). It is remotely executing and global, always on, and endlessly configurable. It is concurrent - a great computer expression - which means that everything happens in parallel. It is self-configuring, meaning it constantly reconfigures itself on the fly, and increasingly it is also self-organizing, self-architecting, and self-healing" (Arthur, 2011, p.2).

evaluate and save recorded data, and actively or reactively interact both with the physical and digital world; are connected with one another and in global networks via digital communication facilities (wireless and/or wired, local and/or global); use globally available data and services; have a series of dedicated, multimodal human-machine interfaces"(Acatech, 2011, p.15).

Another definition of CPS can be found in Lee (2015), for which CPS are defined as:

"(...) an orchestration of computers and physical systems. Embedded computers monitor and control physical processes, usually with feedback loops, where physical processes affect computations and vice versa" (Lee, 2015, p. 4837).

CPS allow not simply the union, but the complete integration between the physical world and the "cyber", the virtual world, combining engineering models and methods with mechanical, environmental, civil, electrical, biomedical, chemical, aeronautical, industrial engineering and computer science; this implies that CPS may be applied to a wide range of sectors: automotive systems, manufacturing, medical devices, military systems, assisted living, traffic control and safety, process control, power generation and distribution, energy conservation, HVAC (Heating, Ventilation and Air Conditioning), aircraft, instrumentation, water management systems, trains, physical security (access control and monitoring), asset management and distributed robotics (telepresence, telemedicine); the increasing ubiquity of CPS demands a change in paradigm in engineering science; in other terms, CPS constitute "a new engineering discipline that demands its own models and methods" (Lee, 2015, p. 4838). The increase in the interactions between the physical and virtual worlds makes the 'classical engineering models' unable to provide adequate means of explanation (Braha et al., 2006).

In the literature, there is often some confusion in a precise distinction between CPS and other similar and popular terms, like the Internet of Things (IoT), Internet of Services (IoS), the Industrial Internet, Machine-to-Machine (M2M), the Internet of Everything (IoE); according to Lee (2015), all of these have one main element in common: they express a vision of technology enabling a connection between the physical world and the information world; however, while each of these terms focus on implementation approaches or specific applications (e.g., the "Internet" in Internet of Things, or "Industry" in Industry 4.0), the term CPS is "more foundational and durable than all of these (...) it focuses on the fundamental intellectual problem of conjoining the engineering traditions of the cyber and the physical worlds" (Lee, 2015, p. 4838).

Similarly, Hermann et al. (2015), in addition to the CPS[7], identifies the following key components of 'Industry 4.0': IoT[8], IoS[9], Smart Factory[10], Machine-to-machine communication and Smart Products[11].

[7] CPS are defined also in Hermann et al. (2015) as those technologies enabling the fusion between the physical and the virtual world; the development of CPS is characterized by three main steps: the identification technologies like RFID tags, allowing a unique identification, with storage and analytics being provided as a centralized service; a second generation of CPS equipped with sensors and actuators with a limited range of functions. CPS of the third generation can store and analyze data, are equipped with multiple sensors and actuators, and are network compatible.

[8] IoT is a term initially adopted in 1998 (European Parliament, 2016), and refers to the IT systems (RFID, sensors, actuators, mobile phones) connected to all sub systems (processes, internal and external objects, supplier and customer networks) interacting "with each other and cooperating with their neighbouring 'smart components', to reach common

On the basis of their literature review, Hermann et al. (2015, p. 11) provide the following definition of Industry 4.0:

"Industrie 4.0 is a collective term for technologies and concepts of value chain organization. Within the modular structured Smart Factories of Industrie 4.0, Cyber-Physical Systems monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the Internet of Things, Cyber-Physical Systems communicate and cooperate with each other and humans in real time. Via the Internet of Services, both internal and cross organizational services are offered and utilized by participants of the value chain".

In similar vein, in PCAST (2011, p.9), 'Advanced Manufacturing' is defined as:

"Family of activities that: depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences, for example nanotechnology, chemistry, and biology. This involves both new ways to manufacture existing products, and especially the manufacture of new products emerging from advanced technologies".

The creation of a 'virtual copy' of the physical world opens up to what Lombardi (2017) defines the "physical-digital Multiverse"; in this broader scenario, the product or service cycle must be considered as an unaccountably infinite set of potential sequences, in a constantly evolving techno-economic environment, where systems are able to think autonomously, learn and adapt to changing conditions, and interact with human beings; every aspect of this "knowledge space" is the result of interactions and intersections between numerous knowledge domains, where multi-disciplinarity is one of the main feature of this evolving, unpredictable and multi-scalar environment.

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goals" (Hermann et. al., 2015, p. 9). According to Dr Eric Mounier, Senior Technology & Market Analyst at Yole Développement, "Most of the added value in IoT solutions will come from the processing of the generated data (...) the ratio between electronic components and data processing can reach 1:50 in certain long-term cases!"; a research estimate of ABI has predicted that by 2020, 30 billion of devices will be connected to the internet. According to Hermann et al. (2015), 'smart objects' interacting one other can be considered as CPS and the IoT is the network in which CPS cooperate.

[9] IoS refers to "internal and cross-organizational services which are offered and utilised by participants in the value chain and driven by big data and cloud computing" (European Parliament, 2016, p.22). As described by Hermann et al. (2015), one of the first applications of the IoS is represented by the project SMART FACE in the "Autonomics for Industrie 4.0" developed by the Federal Ministry for Economic Affairs and Energy. The project concerns the automotive industry and consists of the adoption of flexible modular stations connected by automated guided vehicles, which can move autonomously, knowing the specific custom made configuration; this production configuration is made possible by the use of the IoS; it is likely that this principle will be extended in the future from the single factory to the entire production system, to manufacture products or compensate production capabilities.

[10] The Smart Factory is a factory can be defined as 'smart' when CPS communicate over the IoT and assist people and machines in the execution of their tasks (Hermann et al., 2015). In simple terms, 'Smart Factory' and the related term 'Factory of the future' synthesizes the set of ICT technical innovations which integrate in the manufacturing processes. An example of a "smart factory" is the "Festo Scharnhausen Technology Plant": employees interact safely with flexible robots, taking over health risks assembly tasks on behalf of the human beings; they have adopted a holistic energy transparency system, which is able to track all the energy flows and consumptions; service engineers use tablets as main working tool that works through an app, detecting and rectifying machine disorders and faults in rapid timing. This plant won in December 2016 a special prize of the Lean & Green Management Award 2016, due to its special ability to integrate the lean management to the 'environmental aspects'.

[11] Machine-to-machine communication and Smart Products are considered, respectively, an enabler of the Internet of Things and a subcomponent of CPS.

Design and principles

Industry 4.0 works thanks to the following key principles (Hermann et al., 2015; Acatech, 2013; European Parliament, 2016): Interoperability[12], Virtualization[13], Decentralization[14], Real-Time Capability[15], Service orientation[16] and Modularity[17]. Thanks to these basic principles, the factory will be able to incorporate their machinery, warehousing systems and production facilities in the shape of CPS, making it possible to implement: Horizontal integration[18], Vertical integration[19] and End-to-end solutions[20].

In the specific context of the manufacturing industry, the European Parliament (2016) highlights the changes in products, processes and business models deriving from the digitalization of manufacturing: the advanced automation in production generates an increased flexibility in production, making use of configurable robots and providing a variety of different products that can be produced in the same production facility; mass customization will allow the production of small lots, due to the ability to rapidly configure machines to adapt to customer-supplied specifications and additive manufacturing[21]; digital designs and virtual modelling of manufacturing process can reduce the time between the design of a product and its delivery; the integration of product development with digital and physical production is associated to large

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[12] It is an enabler of Industry 4.0, allowing companies, CPS and humans to be connected over the IoT and IoS; in this way, CPS (work-piece carriers, assembly stations and products) make it possible for humans and smart factories to communicate with each other.

[13] It is the ability of CPS to monitor physical processes, allowing the creation of a ‘virtual’ copy of the ‘Smart Factory’, linking sensor data with virtual plant and simulation models; in case of errors or failures, the system sends alerts to the worker and provides information concerning the following working steps or safety arrangements.

[14] CPS make it possible to ‘decentralize’ production processes, taking decisions autonomously and tracking the whole system at any time; in practice, this means that RFID tags monitor the working steps of machines, in which central planning and controlling are not necessary anymore; in this way, the system can deal with the increasing request of custom made and individual products.

[15] It is the capability to collect, analyze and provide immediate insights in real time concerning the functioning of the factory, whose status is tracked and analyzed permanently.

[16] ‘Service oriented’ architecture makes it possible for companies, CPS and humans to provide services for the entire value chain. Thanks to this property, production process operations can be done on the basis of custom made preferences.

[17] It is the flexible adaptation of smart factories to changing requirements by replacing and expanding individual modules; this feature implies that modular systems can be replaced according to changing product characteristics; new modules can be identified and can be used automatically thanks to the IoS.

[18] It is the integration of the various IT systems in different stages of the manufacturing and business planning processes, involving an exchange of materials, energy and information both within the company (e.g. inbound logistics, production, outbound logistics, marketing) and between several different companies (value networks).

[19] It is the integration of the various IT systems at the different hierarchical levels (e.g. the actuator and sensor, control, production management, manufacturing and execution and corporate planning levels).

[20] It means that the digital integration of engineering across the entire value chain is a result of both horizontal and vertical integration.

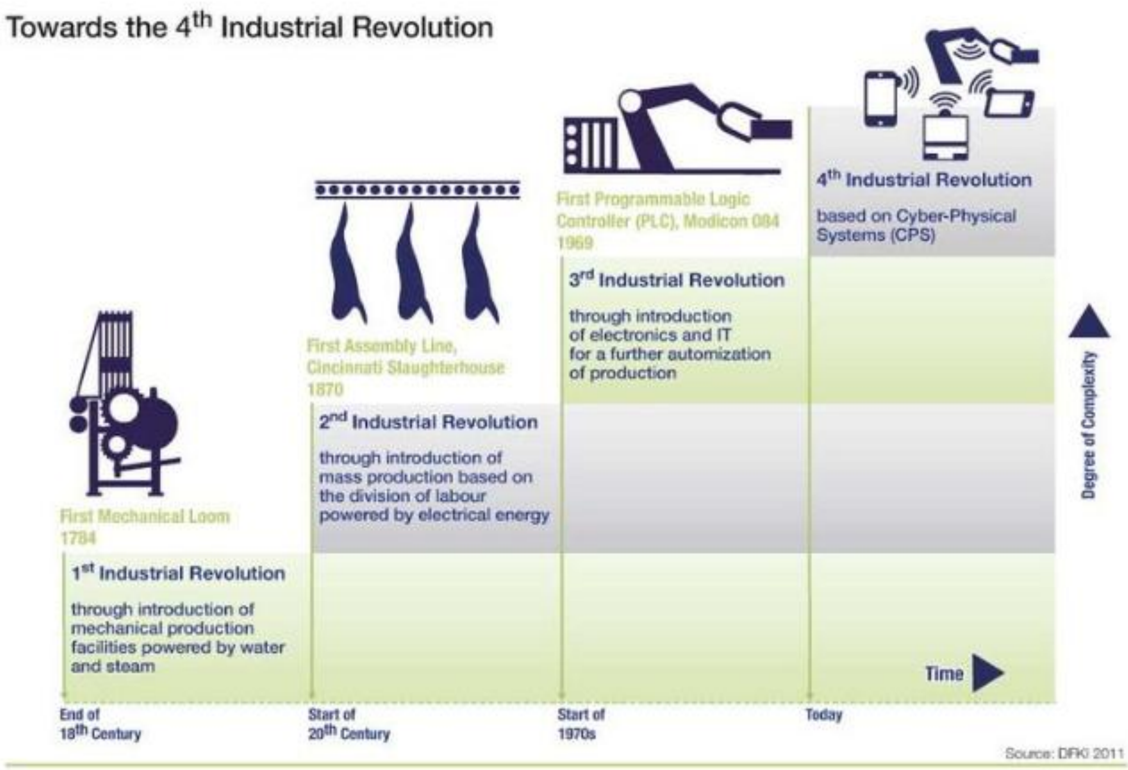
[21] Flexibility stimulates innovation, since prototypes or new products will be produced quickly without complicated retooling or the setup of new production lines; speed with which a product can be produced will also improve and customers will be much more involved in the design process, sometimes providing their own designs that can be produced quickly and cheaply.

improvement in product quality, with reduction in error rates[22]; productivity can increase through the use of advanced analytics in predictive maintenance programmes, reducing machine failures[23].

The European Parliament (2016), drawing on the survey carried on in 2013 and contained in Acatech (2013), underlines some main preconditions which are required for the adequate implementation of 'Industry 4.0': the standardisation of systems, platforms, protocols, connections, interfaces and a cooperative approach to business models with an adequate degree of openness. It underlines the 'systemic' nature of these transformation processes and the need of a proper cooperation between public and private players in order to manage the multiple challenges behind them.

Table 1 provides some of the main definitions of 'Industry 4.0', according to the most relevant contributions on the topic.

Figure 1: The Fourth Industrial Revolution



Source: Acatech, 2013

[22] Data derived from sensors can be used to monitor every piece produced rather than using sampling to detect errors and error-correcting machinery, adjusting production processes in real time, through big data analytics techniques; the increase in quality has positive effect in the reduction of costs and in the increase in competitiveness.

[23] Companies will be able to organize 'lights out' factories where automated robots will continue the production without light or heat, while the staff has gone home. In the Netherlands, the company Philips produces electric razors in a 'dark factory' with 128 robots and just nine workers, who provide quality assurance.

Figure 2: Design and principles of 'Industry 4.0'

	Cyber-Physical Systems	Internet of Things	Internet of Services	Smart Factory
Interoperability	X	X	X	X
Virtualization	X	-	-	X
Decentralization	X	-	-	X
Real-Time Capability	-	-	-	X
Service Orientation	-	-	X	-
Modularity	-	-	X	-

Source: Hermann et al. (2015)

Table 1: Main definitions of 'Industry 4.0'

DEFINITION	SOURCE
A paradigm shift . . . made possible by technological advances which constitute a reversal of conventional production process logic. Simply put, this means that industrial production machinery no longer simply "processes" the product, but that the product communicates with the machinery to tell it exactly what to do.	GTAI (2015)
'Advanced Manufacturing' is a family of activities that: depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences, for example nanotechnology, chemistry, and biology. This involves both new ways to manufacture existing products, and especially the manufacture of new products emerging from advanced technologies.	PCAST (2011)
Industrie 4.0 is a collective term for technologies and concepts of value chain organization. Within the modular structured Smart Factories of Industrie 4.0, CPS monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the IoT, CPS communicate and cooperate with each other and humans in real time. Via the IoS, both internal and cross organizational services are offered and utilized by participants of the value chain.	Hermann et al. (2015)
Industry 4.0 is the digitization of the manufacturing sector, with embedded sensors in virtually all product components and manufacturing equipment, ubiquitous Cyber-Physical Systems, and analysis of all relevant data.	McKinsey (2015)
The term 'Industry 4.0' encapsulate a vision of the future for which the manufacturing industry, will augment its competiveness and efficiency thanks to the digital technologies allowing the interconnection and cooperation of their resources (plants, people, information), both inside the factory and along the entire value chain.	Osservatorio Smart Manufacturing (2015)
Industry 4.0 describes the organisation of production processes based on technology and devices autonomously communicating with each other along the value chain: a model of the 'smart' factory of the future where computer-driven systems monitor physical processes, create a virtual copy of the physical world and make decentralised decisions based on self-organisation mechanisms.	European Parliament (2016)
Industry 4.0 is the term more frequently adopted to indicate a serious of rapid technological transformations in the design, production and distribution of systems and products. In particular, it describes the organization of productive processes based on technology and devices communicating with each other (own translation).	X Commissione Permanente (2016)

Source: author's elaboration

KETs

The degree of complexity of the current paradigm shift grows more than proportionately, with respect to previous revolutions: not a single technology is taken into account, but a bundle of different technologies, whose combination modifies radically the way products, processes and business models are conceived. The literature review of some of the main contributions analyzed (Osservatorio Smart Manufacturing, 2015; CNFI, 2015; Piano Nazionale Industria 4.0, 2016; Roland Berger, 2015; Schwab, 2016; MGI, 2013) shows that not a unique classification of KETs characterizing the 'fourth industrial revolution' is identified. Table 2 provides a comparison of the main KETs identified among these contributions.

Osservatorio Smart Manufacturing (2015) indicates six main enabling technologies; three are closer to the 'Information Technology' domain: IoT/Smart Objects, the possibility of each object to be "smart" and "intelligent", meaning to be identified, localized, monitored and "connected" through standard communication protocols[24]; Manufacturing Big Data, the set of IT methods able to analyze growing volumes of structured transaction data, including other forms of data that are often left untapped by conventional business intelligence and analytics programs[25]; Cloud Manufacturing[26], the full open and on demand access to IT infrastructural platform or applicative services, supporting the productive processes and management of the Supply Chain.

The other three KETs are linked to the 'operational technology' domain: advanced Human Machine Interface (HMI) devices for the acquisition and/or channelling of vocal, visual and tactile data, including display touch, scanner 3D, augmented reality devices, wearables for machine interactions; advanced automation, advanced production automated systems able to interact with the surrounding environment, with self learning and automatic driving mechanisms, the use of vision techniques and patterns recognition interacting with other operators; additive manufacturing, commonly known as 3D printing, opposed to subtractive manufacturing technologies, working by adding successive layers of material laid down in different shapes until the final design is realized[27].

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[24] The applicative domain of the Internet of Things concerns every level of human activity (homes, buildings, environments, cities, agriculture and health care); in the manufacturing industry, it concerns CPS.

[25] Data analytics visualization, simulation and forecasting are finalized at optimizing and exploiting the information laying behind the data for rapid decision making.

[26] Cloud Manufacturing includes the virtualization of the physical resources necessary for the machines inside the fabrics, data and processes on e-execution platforms and e-collaboration in cloud; these include internet click stream data, web server logs, social media content, text from customer emails and survey responses, mobile-phone call-detail records and machine data captured by sensors connected to the internet of things.

[27] Common to all the additive manufacturing technologies is the use of a computer, 3D modelling software (Computer Aided Design (CAD)); the data are read from the CAD file and the printing processes work by laying down and adding successive layers of material; in recent years, there have been important advances in additive manufacturing technologies: selective laser sintering, electron beam melting, fused deposition modelling, stereolithography; also the types of materials used may vary from plastic, to metals, with good finishing and mechanical resistance. The possible applications of the additive manufacturing processes are: prototyping, supporting product development processes, static simulation processes, manufacturing of final products, maintenance and repair of damaged parts, tooling for molds, patterns, jigs, and features.

In contrast to Osservatorio Smart Manufacturing (2015), Roland Berger (2015) uses the term 'Cobotics' referring to collaborative robotics between humans and machines and refers explicitly to 'collaborative maintenance' to indicate the techniques supporting the conditions of in-service equipment in order to predict the right moment in which maintenance should be performed, with important savings in terms of costs and times maintenance. Also Piano Nazionale Industria 4.0[28] (2016) provides a similar classification, but explicitly mentioning "Cybersecurity" as a KET, referring to the security in network operations and on open systems.

While these are particularly inherent to the value chain organization, other works like the Research and Innovation Road Map of the National Intelligent Factories Cluster[29] (CNFI, 2015), Schwab (2016) and MGI (2013) adopt a broader perspective, including other KETs characterizing the present transformation processes. In addition to the technologies already mentioned, CNFI (2015) adds two main categories linked to advanced materials and sustainable manufacturing: production and deployment of innovative materials, including materials for external environments, materials for production and energy storing, materials for application to construction sector, materials for display, bio-based and eco-compatible materials, multi-functional materials, micro-nano-materials, renewable high performance materials; technologies for sustainable manufacturing, including sustainable manufacturing processes and de-manufacturing factories.

Moreover, MGI (2013) and Schwab (2016) mention the important innovations in the biological realm, in particular the next generation genomics. The increase amounts of data will make precision medicine possible, enabling the development of highly targeted therapies to improve treatment outcomes[30]. "It is in the biological domain where I see the greatest challenges for the development of both social norms and appropriate regulation. We are confronted with new questions around what it means to be human, what data and information about our bodies and health can or should be shared with others, and what rights and responsibilities we have when it comes to changing the very genetic code of future generations" (Schwab, 2016, p. 23). According to MGI (2013), next-generation genomics may be defined as "the combination of next generation sequencing technologies, big data analytics and technologies with the ability to modify organisms, which include both recombinant techniques and DNA synthesis (that is, synthetic biology)" (MGI, 2013, p. 87).

[28] In this report, the classification provided includes the following: Advanced Manufacturing Solutions; Additive Manufacturing; Augmented Reality; Simulation; Horizontal/Vertical Integration; Industrial Internet; Cloud; Cyber-security; Big Data and Analytics.

[29] CNFI is one of the most important examples at national level of collaboration between companies, universities, research centres and associations working together on the themes related to the 'Factory of the Future', in order to strengthen the Italian leadership in the manufacturing industry.

[30] IBM's Watson supercomputer system is an interesting example of the level of advance reached by these technologies, being able to recommend in few minutes, custom made treatments for cancer patients on the basis of the patients' histories of disease and treatment, scans and genetic data. Next generation genomics will involve health care, agriculture and the production of substances such as bio-fuels, reaching a potential impact of $700 billion to $1.6 trillion a year by 2025; 80% of this amount will derive from the extension lives thanks to faster disease detection, the discovery of new drugs and tailored made treatments; in agriculture, plant genomes will generate a new generation of genetically modified crops, optimizing the farming process according to the seed's genetic characteristics; the possibility to modify the gene-sequences will generate high-value substance like bio-fuels (MGI, 2013, Schwab, 2016).

This broader perspective which takes into account a wide spectrum of fields introduces to the following paragraph dedicated at summarizing the impact and the main challenges of this 'fourth industrial revolution' in terms of economy and businesses.

Table 2: KETs of 'Industry 4.0'

Osservatorio Smart Manufacturing (2015):	**Piano Nazionale Industria 4.0 (2016):**	**Roland Berger (2016):**	**CNFI (2015):**	**Schwab (2016):**	**MGI (2013):**
Industrial Internet of Things/Smart Objects	Advanced Manufacturing Solutions	Virtual industrialization	Advanced Production Processes	Autonomous vehicles	Mobile Internet
Manufacturing Big Data or Industrial Analytics	Additive Manufacturing	Interconnected machines & plants	Mechatronics for Advanced Manufacturing	3D printing	Automation of Knowledge work
Cloud Manufacturing	Augmented Reality	Active sensors	Methods and Tools for simulation, planning and forecasting	Advanced robotics	The Internet of Things
Advanced Automation	Simulation	Automated logistics/ Internet of Things	ICT for manufacturing	New materials	Cloud Technologies
Advanced HMI	Horizontal/Vertical Integration	Smart machine	Strategies for Manufacturing Management	Internet of Things	Advanced Robotics
Additive Manufacturing	Industrial Internet	Additive manufacturing and Cobotics	Production and deployment of innovative materials	Genomics	Autonomous and near autonomous vehicles
	Cloud	Conditional maintenance	Technologies for sustainable manufacturing	Neurotechnologies	Next generation genomics
	Cyber-security	Augmented operator	Technologies and methods for human-centric factories		Energy storage
	Big Data and Analytics	Learning organization			3D printing
					Advanced materials
					Advanced oil and gas exploration recovery
					Renewable energy

Source: author's elaboration

2.1.2. Impact of 'Industry 4.0' in the economy and in business models

The analysis of the impact of these disruptive changes is complex and difficult, due to the high level of uncertainty and unpredictability characterizing the evolution of multi-dimensional processes and systems (Lombardi, 2017). Schwab (2016) identifies four main levels of analysis in order to describe the pervasiveness of these techno-economic transformation processes: the economy, business, society and the individual[31]. Among the numerous economic indicators traditionally used, two main relevant dimensions of this economic impact are taken into account (Schwab, 2016): growth and employment.

The Economy - Growth

The debate concerning the impact of 'digitalization' on economic growth may be understood in the context of the analysis of the recent global trends[32]; the 'Great Recession' caused a downturn in the economic growth rate, which shifted from 5% to 3-3.5%, with no signs of recovery; this slow trend may be explained on the basis of two main factors: ageing and productivity. The ageing phenomenon is causing a meaningful increase in the dependency rate of the elder part of the population and generating new consumer categories and target groups (CNFI, 2015; European Parliament, 2016; TSB, 2012); drawing on an analysis of Roland Berger (2011), CNFI (2015) highlights that in 2020, over 25% of the population in developing countries will be based on over-60-years old, reaching the 29% by 2030; as already mentioned, this increasing trend lays the foundation for the development of advanced technologies supporting longer, healthier and more active lives; "the growing, ageing population places additional burdens on the state sector (such as retirement and healthcare provision) but also offers significant opportunities for new markets, particularly medical and pharmaceutical" (TSB, 2012, p. 13).

In relation to productivity, Schwab (2016) underlines what is defined as today's great economic enigmas of the 'Great Depression', the so-called 'productivity paradox': despite the exponential growth in technological progress and investments in digital technologies, productivity, either measured as 'labour productivity' or as 'total factor productivity', has not increased at the same pace. McAfee and Brynjolfsson (2011) in their book "The Second Machine Age", argue that the labour productivity rate increased until 2000 and started declining from the 'Great Depression'. Lombardi (2017a) recalls that it is not the first time in the history that this 'paradox' is being observed; Robert Solow has been one of the first economists observing this phenomenon giving the name to the well known paradox, the "Solow's Paradox" synthesized by the citation "You can see the computer everywhere but in the productivity statistics" (New York Book Review, July 2, 1987). In fact, some years after, Paul David showed that it took many decades for the introduction and diffusion of electrical energy to reveal its full potential in terms of productivity. This is because techno-economic shifts usually involve multiple players interacting in different ways at different social, economic,

[31] This paragraph will deepen in particular the impact of 'Industry 4.0' on the economy and on businesses.
[32] In general terms, this debate is characterized by two main opposing positions: on one hand, the so called 'techno-pessimists', arguing that the contributions of the digital revolution are almost over, on the other hand, the so called 'techno-optimistic' claiming that technology and innovation will soon generate an increase in economic growth (Schwab, 2016)

technical, institutional and cultural levels, taking many years to fully realize (Perez, 2010; Lombardi, 2017a)[33].

Another controversial aspect in the relationship between productivity and technological evolution which is worth to be mentioned is what Jeremy Rifkin calls the 'Zero Marginal Cost Society': the ongoing paradox at the heart of capitalism generated by the IoT. Large segments of economic life are characterized by increasing productivity and lower, almost zero, marginal costs. Today, many goods and services are 'non rival' with zero marginal costs and highly competitive thanks to the diffusion of digital platforms.

In particular, Schwab (2016) underlines three main points which suggest a potentially positive trend in productivity increase, linked to advanced digital technologies: the possibility to better satisfy customers' needs, thanks to the increase in the ability of communities and individuals to be always connected all over the world; the capacity of advanced renewable sources of energy technologies to address negative externalities related to the climate and environmental emergencies; the need to change economic and organizational structures in order to fully realize the efficiencies of digitalization[34].

These effects may not be properly accounted by traditional economic indicators; that's why Schwab (2016) suggests the need for new 'lenses of analyses' in economic theory in order to fully understand these transformation processes. "(...) I believe that the combination of structural factors (over-indebtedness and ageing societies) and systemic ones (the introduction of the platform and on-demand economies, the increasing relevance of decreasing marginal costs etc..) will force us to rewrite our economic textbooks" (Schwab, 2016, p. 34).

The Economy - Employment

The other crucial dimension of economic growth which needs to be discussed is the effect of the 'fourth industrial revolution' on employment. The three main features of this shift mentioned, speed, breadth and depth, and the disruptive changes in the entire systems, put labour and employment in a particular critical light; whether advanced automation will determine a downturn or a positive development of the labour market in the long run, is still a matter of animated debate among the experts. Schwab (2016) identifies two main competing effects of technology on employment: a destruction effect, for which advanced automation will replace human workers, forced to reallocate their skills elsewhere; a capitalization effect, in which the demand for new goods and services will generate new occupations and businesses.

[33] Another phenomenon exacerbating the so-called 'productivity paradox' is the rising income inequality occurring also in many developed countries like the U.S. McAfee and Brynjolfsson (2011) argue that a sign of income inequality is the decreasing median in income mostly during the years of higher growth of productivity and innovation diffusion.

[34] Moreover, some of the most important consulting companies tend to agree on the positive effects of digitalization on productivity. For example the BCG (2015) provides a quantitative understanding of the potential impact of 'Industry 4.0' on economic growth taking Germany as an example. In relation to productivity, the company estimates that in the following five to ten years, 'Industry 4.0' will cause an increase in productivity between 90 and 150 billion; productivity improvements on conversion costs, excluding the costs of materials will vary between the 15-25%; taking into account the costs of materials, the productivity gains will vary between the 5-8%; these improvements will change according to the industry, for example the industrial component is expecting the biggest impact in terms of productivity gains.

There are two main opposing positions among the experts concerning the impact of technological evolution on the labour market. The first who believe that the 'destruction effect' will be higher than the 'capitalization effect', predicting a massive unemployment to occur; the second position stresses that the 'capitalization effect' will be higher than the 'destruction effect', leading to a new era of prosperity and a new generation of occupations.

According to the World Economic Forum (2016) there will be an employment impact of more than 5.1 million jobs over the period 2015-2020, with a total loss of 7.1 million jobs, two third of which concerning in particular office and administration and white collar office jobs, in favour of jobs in Computer, Mathematical, Architecture and Engineering fields. However, this negative impact on employment is counterbalanced by a positive effect on employment of some key technologies, IoT, Data Analytics and Robotics, also thanks to some socio-demographic trends: the increase in the middle classes of the developing countries, the increasing aspirations of women, the need to face the climate and environmental challenges.

Frey and Osborne (2017) have tried to quantify the effects of technological innovation of unemployment, arguing that employment will grow in high income cognitive and creative jobs, and will greatly diminish for middle-income routine and repetitive jobs; they list the professions who are most prone to automation, like telemarketers, tax preparers, insurance appraisers, legal secretaries, couriers and messengers, real estate brokers, and the least prone to automation, like mental health social workers, choreographers, physician and surgeons, human resources managers, anthropologists, archaeologists and computer systems analysts. In terms of competences required by the enterprises, important changes are expected: in particular, a higher importance of professions linked to design, software, chemistry of new materials, plant maintenance, an increase in the demand of technical and 'creative' professions and less non-qualified labour (Sole24 Ore, 2015).

In the manufacturing industry, the Boston Consulting Group[35] underlines that, while the number of physically demanding routine jobs will decrease, the number of jobs requiring flexible responses, problem solving, and customization will increase; they provide some examples of how Industry 4.0 will modify the nature of work: the automotive assembly line worker will benefit of automation, through robotic devices supporting him to relieve from physically demanding tasks, improving ergonomics; mobile service technician will benefit of predictive maintenance, by remotely viewing a stream of real-time data on machine performance, identifying proactively defects, ordering spare parts before arriving at a site, and taking advantage of augmented reality technologies, being able to receive remote guidance, with consistent savings in terms of time spent on each site; industrial data scientist able to extract and prepare data and conduct advanced analytics will be more and more required by the manufacturing industry; robot coordinator will be

[35]See: https://www.bcgperspectives.com/content/articles/technology-business-transformation-engineered-products-infrastructure-man-machine-industry-4/?chapter=4#chapter4

more and more needed for emergency maintenance and supporting older employees in physically demanding jobs[36].

These radical transformations will require the need to take up seriously the challenge of adapting skills and competences to this rapid changing technological environment. It will be necessary to invest heavily in education and training: the so called 'digital skill' will not be enough, it will be necessary the capacity to manage complex manufacturing systems; in other terms, we are going towards a 'manageralization' of employees that will interact in a complex way with machines (Fotina, 2015).

Lombardi (2017b) identifies four main lines of action going in this direction: the adoption of a vision focused on trans-disciplinary projects; the support of learning *project-based* processes, in line with the 'circular economy' principles, which are closer and closer to an integrated vision of product life cycles, where materials, energy and information are fully integrated; the need to consider economic processes in the context of dynamic and open systems; the need to 'think systemically' implying the need to adopt new business models and managerial competences. "Given the increasing rate of change of technologies, the fourth industrial revolution will demand and place more emphasis on the ability of workers to adapt continuously and learn new skills and approaches within a variety of contexts" (Schwab, 2016, p. 45).

Another aspect to be taken into account when analyzing the relationship between technological development and employment is the 're-shoring phenomenon'; many studies (Fratocchi et al., 2016; Bailey and De Propris, 2014) reveal that in recent years the tendency of re-shoring and near-shoring has increased, due to the rise in the cost of labour in some developing countries and the benefits linked to shorten the supply chain, bringing back manufacturing activities to the native countries[37]. If the access to low-cost labour no longer drives the competitiveness of developing countries, this scenario poses severe challenges to the need to rethink their business models and strategies of industrialization (Schwab, 2016).

[36] In the U.S., the figure of the Chief IoT Officer is emerging, integration between the Chief Information Officer and the Line Business Manager, with competences linked to cybersecurity, cloud and big data; a figure that will be central in the digitalization process, managing the radical changes in business and organizational models of the enterprises (Rusconi, 2016).

[37] While according to some literature (Bailey and De Propris, 2014), re-shoring and off-shoring appear to be mostly driven by cost-related considerations, the work of Fratocchi et al., (2016) highlights also the importance of value-related elements. They provide a literature review on the main drivers of 're-shoring', identifying 24 main motivations, partly overlapping with existent findings in the literature, which may be summarized in four main categories: customer-perceived value, cost efficiency, internal and external environment motivations. Customer perceived value is generally associated to delivery time, customers' service improvement, proximity to customers, "made-in" effect and poor quality of off-shored production; cost efficiency is generally linked to logistic costs and total costs of sourcing, off-shored activities' control complexity and labour costs' gap reduction; motivations linked to the internal environment are firms' global reorganization, and to external environment are subsidies for relocation.

The Business Models

As highlighted in Lombardi (2017), the general framework needed in order to understand the changes in business models of the Industry 4.0 paradigm is the 'circular economy[38]'.

Lombardi (2017) underlines that "disruptive technologies" make it possible to overtake the 'linear model' based on the *take-make-dispose* paradigm "closing the loop", that is, rethinking growth without consequences on the natural resources, the stock of 'natural' capital. The transition towards the 'circular economy' can be done through the so-called RESOLVE[39] business actions, which are described in McKinsey (2016). Moreover, other approaches may be included in the context of the Circular Economy: Life Cycle Assessment (LCA), a "systemic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle", following precise standards (ISO14040, ISO14044).

The integration of the LCA approach with social priorities, leads to the so-called SLCA approach, which is defined as "a social and socio-economic Life Cycle Assessment (S-LCA), a social impact (and potential impact) assessment technique that aims to assess the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle encompassing extraction and processing of raw materials; manufacturing; distribution; use; re-use; maintenance; recycling; and final disposal" (UNEP, 2009, p.37). The Industrial Symbiosis defined by Chertow (2000, p.314) as the "collective approach to competitive advantage involving physical exchange of materials, energy, water, and/or by-products"; the approach "From Cradle to Cradle" is based on three main assumptions: waste considered as food; the use of the solar energy; the importance of diversity[40].

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[38] A communication of the European Commission of the 2-7-2014 (COM, 2014) provides some guidelines detailing what circular economy is about. Generally, the 'circular economy' is opposed to the 'linear model', which dominated the economies since the industrial revolution and was based on the assumption of off-limit abundance, availability, easy to source of resources; the increase in demand and competition for finite and scarce resources caused an increase in environmental degradation, which today has become a major threat for the economy; a 'circular' approach to the economy, in which the value of products is kept as long as possible and wastes are reduced, is recognized by the European Commission as one of the ways to implement a smart, sustainable and inclusive growth; circular economy systems make it possible for products, once the end of its life is reached, to be kept inside the economy; the shift towards a more circular economy needs changes in the value chains, from product designs to new business and market models, to new ways of tuning wastes and new modes of consumer behaviour. Circular economy systems may act through the following ways: lightweighting, that is reducing the quantity of materials required to deliver a particular service; durability, that is the increase in the products' useful life; efficiency, that is the reduction of the use of energy and materials in production and use phases; substitution, which means reducing the use of materials which are difficult to recycle in products and production processes; recyclates, through the creation of markets for secondary raw materials; eco-design, the design of products that are easier to maintain, repair, upgrade, remanufacture or recycle; maintenance and repair services, that is to develop the necessary services for consumers; incentivising waste reduction and separation behaviours of consumers.

[39] Regenerate: a set of actions able to keep and enhance the earth's bio-capacity, including the transition to renewable energy, the protection of ecosystems, returning biological resources to nature; Share: the sharing economy concept, which optimizes the full utility of goods, eliminating wastes, sharing resources both in consumption and production and rethinking at the use of inputs along the value chain; Optimize: the reduction of waste energy and materials in the manufacture and in the use of goods; Loop: organic materials are composted in the economy and technical resources are reused; Virtualise: the exploitation of the maximum potentiality of the Internet; Exchange: the process of replacing old technologies with new ones, like for example 3D, electric cars, multi-modal transport systems.

[40] An interesting example of company in which all the basic principles of the 'circular economy' are synthesized has been provided during the conference 'Fabbrica Futuro Bologna", the 8th of June 2016, in the green manufacturing

Schwab (2016) underlines four main effects of the fourth industrial revolution on businesses across different industries: first of all, the changes in consumer expectations; consumers are increasingly at the centre of the digital economy, in which the products are inseparable from the service or the 'experience' they sell and where data sharing will be a necessary part of the value proposition; second, the importance of digital capabilities as a means through which increase the value of organizations' assets: enormous advantage in terms of maintenance, predictive analytics to monitor the performance of assets and saving costs on energy consumption; third, the crucial importance of a collaborative approach to innovation, given the role of customer experience, data sharing and data analytics for asset management and given the enormous speed at which innovation takes place; fourth, the need to introduce new operating models, in order to increase the speed and agility required on the markets[41].

Summing up, there are three main guiding principles which 'Industry 4.0' introduces in the approach to business models (Lombardi 2017): an individual and collective open mindset, without taking as granted the commonly accepted solutions to techno-productive problems, especially if they challenge the consolidated know-how; the need to deepen the knowledge of their business model, calling into question their basic principles through bottom-up processes; the need for systemic thinking, that is the capacity to connect specific and more general elements of the business model at different levels.

"Operating in an increasingly complex and disruptive environment requires the intellectual and social agility of the fox rather than the fixed and narrow focus of the hedgehog. In practical terms, this means that leaders cannot afford to think in silos. Their approach to problems, issues and challenges must be holistic, flexible and adaptive, continuously integrating many diverse interests and opinions" (Schwab, 2016, p. 107).

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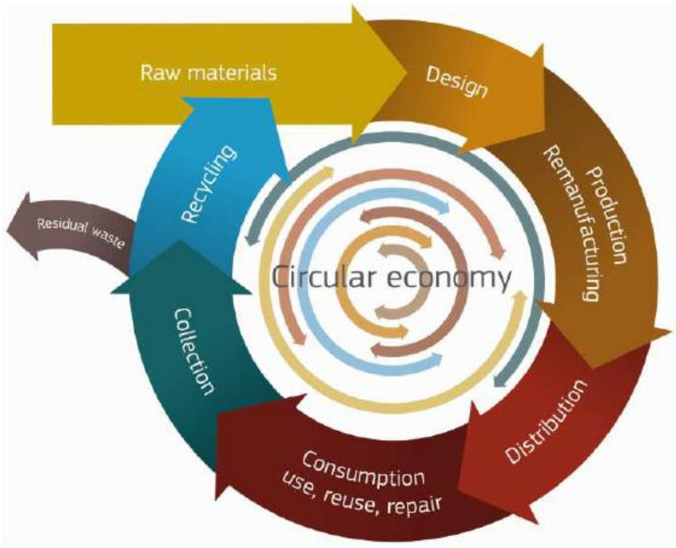
section: Manifattura Maiano S.p.a, a Florentine company leader supplier in the sector of furnishing padding solutions, the mattress in particular; the company realizes hi-performing products in the footwear, eco-friendly thermal sound insulation for construction, the automotive and metallurgic industries, and in the geo-textile and agro-textile industries as well. For the company, textile industry wastes, which are very cheap and abundant in the city of Prato, represent a real resource for the company's competitive advantage. In fact textiles fibres have many properties; at the end of its life cycle, a cloth or textile product can be recycled for different applications: furnishing padding solutions, felt for footwear, eco-friendly thermal sound insulation for construction; "waste is transformed in a new product with a high value added" (Sara Casini, R&D manager, Manifattura Maiano).

[41] "Collaborative innovation is the next big idea that needs to shape up with actionable items, allowing players across the value chains to participate in the emergence of new collaborative business models. Anchored in solid foundations of entrepreneurship, collaborative innovation is the engine of modern, agile organizations capable of creating new capacity, which can pioneer radical new ideas while testing the limits of markets. A true best friend for growth" (Mark Esposito, Professor of Business and Economics, Harvard University Extension School, Grenoble Ecole de Management).

Figure 3: The Circular Economy



Source: COM (2014), The Circular Economy

The important element to be mentioned in relation to the increasing importance of 'collaborative innovation' is the role of ecosystems and digital platforms: the need for enterprises to be consumer centric and to enhance the performance of products through data are leading many companies to focus on the service they are able to offer, rather than on the product itself. In this context, the value creation derives not much from owning the property of assets, but in delivering a service[42]. "The competitive advantage is built on a superior experience, combined with reduced transaction and friction costs. Also, these companies match demand and supply in a rapid and convenient manner, which side-steps the business models of the incumbents (Schwab, 2016, p. 61)".

The possibility to integrate the special characteristics of embedded systems, real-time options and the openness of the system, generate incredibly innovative solutions and applications: digital platforms and company networks have become the new technological challenges of companies developing their competitive strategies[43]. In this radical new techno-economic context, products are more and more *'multi-technology',* as the result of a variable combination of different knowledge domains, ranging from mechanics, electronics, physics and software areas; business environments become more and more hypercompetitive with multi-disciplinary and cross-functional teams, as shown by the biggest worldwide multinationals, which are strongly investing in sectors which are different from the ones they are specialized in (Lombardi 2017)[44]. Boundaries of the firms are becoming more and more 'fuzzy' (Tether, 2002). "The

[42] This is the case of the big multinationals like Amazon, Airbnb, Booking.com, Uber, which earn on delivering a service, without owning any of the goods they use to create value.

[43] In Acatech (2015), ecosystems are defined as "cross-company strategic partnerships between several different stakeholders, users, organisations that make use of objects (smart products) and are organised to form a business network; an ecosystem delivers a value proposition that is greater than the sum of the value propositions of the individual companies that form part of the ecosystem" (p.37).

[44] "The innovative dynamics are radically changing: it is not longer convenient to specialize in the sector you are good at, but, precisely because you are good in that sector, you must explore others: It is the case of Toyota investing in Uber,

potential for change of digital ecosystems is a consequence of the overcoming of the traditional boundaries between companies and is therefore an unknown space in which the sources of change can be both endogenous and exogenous (...) this does not mean that companies will disappear, but will evolve in something very different from the past: they tend to become strategic nucleus, organizing systematic variable combinations of components of the sequence of operations" (own translation, Lombardi, 2017, p. 65).

2.1.2.1. The role of digital platforms: some example applications

Acatech (2013) provides multiple examples of the importance of digital ecosystems for today's business in a variety of contexts: manufacturing, logistic services, energy services, farming and health. The following paragraphs are dedicated at summarizing some example applications of the role of digital platforms in these fields.

Smart Manufacturing

Acatech (2013) provides several examples highlighting the potential of CPS in the manufacturing industry in terms of gains in efficiency, flexibility and cost effectiveness.

A first example concerns the ways through which energy consumed by a vehicle body assembly line can be reduced, while it is not consumed; in fact, at present time, most part of the production lines run and consume high levels of energy during breaks, weekends and shifts, where there is no production. In the 'Industry 4.0' perspective, the reduction of energy consumptions will be made possible through robots that will be powered down through a kind of standby mode, known as Wake-On-LAN mode. Moreover, many advantages derive from the adoption of end-to-end systems engineering across the entire value chain; in fact, today, the management of the information through the entire value chain is prevalently organized through IT support systems working through a variety of interfaces, with low possibility to integrate the information systems across the entire value chain, and a reduced capability to implement big data analytics; as a result, the customer is not able to select all of their products' functions and options; thanks to CPS, it will be possible to cover every aspect of the value chain, from the customer requirements to the product architecture and final manufacturing of the finished product in an end-to-end engineering tool chain.

End to end systems engineering are functional to a manufacturing system, where single customers' requirements can be more easily met. For example, today the automotive industry is characterized by static production lines, which are difficult to reconfigure including new production variants; the Manufacturing Execution Systems (MES) are usually adopted, which however, do not easily allow for custom made options: customer requests are difficult to be included in the production processes; CPS will make it possible for dynamic production lines to emerge, mixing and matching the equipments with which vehicles are fitted; for example, it will be possible to fit a seat from a different vehicle, without following constrained and prescribing timings.

Google investing in the electric car, Lego investing in Kindergartens." (Federica Dallanoce, ADACI, Fabbrica Futuro, 8th June 2016, Bologne).

A further example application concerns telepresence services: remote services provide customers with the possibility to have fast and efficient support by accessing and controlling machines; this process today requires a significant amount of management work, since the service needs to be provided individually for each customer. The Industry 4.0 perspective will make it possible for manufacturing systems to operate like ‘social machines’, being automatically connected to digital cloud based platforms, where the experts will be able to implement the maintenance services more efficiently, through mobile devices; this shift from the machines to the portals has the purpose to ensure that these services are made in the shortest time possible, with productivity gains.

A final example concerns the unexpected event of a sudden change of supplier, due to a political crisis or natural disasters, which are out of the manufacturer’s control; this event may cause inefficiencies in the production processes in terms of meaningful additional costs, delays in the production, caused by the need to change the supplier; this event is today supported by IT just partially; Industry 4.0 will make it possible to assess, by running simulations, the impact on production and support the finding process of an alternative supplier in a relatively rapid timing, choosing among different suppliers with different capacity in real time, in the supplier cloud. Ultimately, IoT makes it possible to implement the following operations: monitor the status of assets, parcels, people in real time, throughout the entire value chain; control how these assets are performing and effect changes in what they are doing; automate business processes in order to eliminate manual interventions; have better quality in the services and predictive capacity; optimize how people, systems and assets collaborate and apply data analytics to the whole value chain.

In this new scenario, service platforms will make it possible to realize ‘smart manufacturing’ processes (Acatech, 2015); in order to overcome the problem of silos, which are present throughout the horizontal physical value chain, (the manual management of plant operators acting as data intermediaries and managing the different businesses partners, usually when a failure has occurred and the under-utilization of big data analytics) service platforms will make it possible to realize substantial productivity gains, thanks to the use and analysis of data available in a collaborative environment, with predictive actions within the ecosystem. Moreover, service platforms might overcome a second type of problem: the high costs for manufacturing systems operators, related to the acquisition and optimisation of technology data and staff, materials and machinery needed to perform the necessary tests; the transaction platform will make it possible for plant operators to automatically acquire any missing data through a cloud service with automated ordering and delivery. In this way, costs related to staff, machinery, and materials can be saved, and flexibility and cost effectiveness may be improved.

Smart Logistic Services

Interesting benefits of digital platforms are evident in the context of logistic services; in this case, efficiency gains are obtained by improving the coordination between different stakeholders: sea port operators, container terminal operators, logistics network operators, port management, shipping companies, car park operators, heavy goods transporters and a variety of other firms and service providers. The integration of different players makes it possible to optimise logistic processes, thanks to real-time oriented consolidation, storage and analysis of data on infrastructures, traffic and logistic objects and processes (Acatech, 2015). An example of 'smart logistic service' is represented by the Seoul City Transportation Information Center (TOPIS); it was initially a bus management system and today provides efficient public transportation services through the management of information on the public transportation of Seoul, gathering big data from streets, buses, taxis and citizens using GPS devices, loop detectors, road sensors, videos and citizen reports. This system makes it possible to increase transit efficiency, reducing traffic and improving customer satisfaction (DHL, 2015). "In essence, Internet of Things in the world of logistics will be about "sensing and sense making". "Sensing" is the monitoring of different assets within a supply chain through different technologies and mediums; "sense making" is concerned with handling vast amounts of data sets that are generated as a result, and then turning this data into insights that drive new solutions" (DHL, 2015, p.7).

Smart Energy Services

The current energy system is characterized by several sources of inefficiency (Acatech, 2015): a low level of dynamic cooperation between players on energy related matters; the lack of energy coordination services in the fields of healthcare and security; the presence of high technical entry barriers to the electricity market for small-scale power generation operators; the lack of awareness of customers' single needs; the restriction of information access and control functions to establish market players in regulated market processes.

In the electrical energy sector, there is much debate around the need to shift towards the so-called 'smart grid' electric energy distribution system; in fact, the traditional electrical energy delivering methods have contributed negatively, especially in recent years, to climate and environmental changes, requiring the need for meaningful adjustments. Together with the adoption of clean renewable power generation of pulp and paper industry, 'smart grid' is recognized as the new challenge of the modern electrical industry and is defined as "a concept for modernizing power systems by integrating the electrical and information technologies" (ABB, 2010, p.2). The combination between electrical and information domains and the shift from a 'centralized' to a 'decentralized' system of energy distribution give the system the following properties: "adaptive", able to rapidly respond to changing conditions; "predictive", capable to identify potential faults before occurring; "integrated", thanks to real-time communications and control functions; "interactive" between the consumer and the market; "optimized", in terms of reliability, availability, efficiency and economic performance; "secure", preventing external attacks and occurring deficiencies.

Moreover, these principles may be extended to all kinds of energy resources distribution processes, including petroleum, natural gas and water. In DHL (2015), an interesting example is provided in the water utility sector. Hagihon, Israel's largest municipal water utility company, has adopted smart devices to improve the water-system management maintenance, reducing water losses and increasing profitability. This was possible thanks to pump and in-ground sensors, allowing easy tracking of water pressure and flows; a control and data acquisition system, based on sensor data analysis; a geographical information system, providing a real time map of current conditions; fixed acoustic sensors, combined with mobile, cloud and GPS technology, able to identify underground water leaks, with ERP and mobile apps supporting field technicians productivity. The impressive cost savings were also the result of a significant increase in labour efficiency: data collection, which initially was conducted manually, is done by the use of sensors.

A digital platform (Acatech, 2013) for 'smart energy services' could make it possible to facilitate some important operations: the implementation of energy services for customers, the improvement of information on customer requirements for energy suppliers and energy service providers, the management of virtual power plants for power generators operators, the brokerage of electricity storage capacity, the coordination of energy communities, the support of home care services by using sensor technology adopting selected energy data and sensors, the use of energy data by emergency services, the use of smart energy data by the civil protection services to face eventual crisis situations.

Smart Farming

The Food and Agricultural Organization (FAO) has recently predicted an increase in global population to 9.6 billion people by 2050; production is estimated to grow at the 70% by 2050, in order to keep pace. However, there are several issues representing an obstacle to production growth: the decrease in productivity growth, the low availability of arable lands, climate change, the increasing need of fresh water, and the relatively 'old' people working in the farming industry. In particular, the climate change is considered to affect agricultural activities, giving rise to changes to seasonal events in the life cycles of plants and animals. In this context, digital technologies are identified as one of the main solutions to face these dramatic challenges. 'Smart Farming' or 'precision agriculture' make use of some main technologies like supporting systems, backed up by real time data, providing information at all aspects of farming, not previously possible and enabling better decision making, less wastes and maximum operational efficiency.

The Beecharn Research (2014) identifies six main technologies revolutionizing farming industry: sensing technologies, software applications, communication systems, telematic and positioning technologies, hardware and software systems and data analytics solutions. Seven are the main application areas identified: fleet management, tracking of farming vehicles, arable farming, livestock monitoring, indoor farming, fish farming, storage monitoring, including water and fuel tanks. In each of these sectors, the farmer can have access to a wide range of benefits (Acatech, 2015) like transparency, the management of a more reliable planning, the possibility to have more easily measured process steps, effectiveness and efficiency, with lower fuel consumption, investment and theft protection, networking, integrating partners, suppliers and merchants and flexibility.

Smart Health

One of the main challenges in the health care sector is the ability to interpret the enormous amount of data in the human and biological networks, in order to improve the signal to noise ratio. Roland Berger (2016) outlines some main 'winning digital health principles', in order for this aim to be fulfilled: "interaction", that is the connection of all the relevant stakeholders in the healthcare system; "value added", the use of ‘smart solutions’ which are able to overcome the distance between the healthcare provider and the patient; “platform connectivity”, which brings the patient in ‘connection’ through social media, websites and apps; “data”, taking advantage of comprehensive user data, ensuring accessibility and security; “intelligence”, that is the use of big data to improve the ‘predictive capacity’; “device”, the use of different interfaces to improve patients’ lifestyle; “sensors”, that is the use of wearable sensors able to track physical activity and other health indicators; “pharmaceutical”, that is the addition of a new technology dimension to the core product; “regional”, that is the understanding and the acceptance of local pain points through the adjustment of technology and value added.

Currently, the players of the healthcare system are prevalently operating in closed systems: many silos exist in the delivery of the horizontal physical and digital services. The lack of an integrated and networked system can be overcome by a service platform able to improve the patient diagnosis through the access to innovative services improving the connection to a shared platform, the development of new diagnosis methods through big data analytics, the optimization of the knowledge sharing between the providers and the patients. In this context, open digital platforms may be able to achieve some relevant benefits: cost savings in terms of medication and therapeutic aids, a more efficient medical care, thanks to a decentralized monitoring of patients; centralized data storage, enabling patients to have access to all of their data at any time, consulting doctors anywhere; digital documentation of all health data, enabling quality management and transparency and giving patients better protection (Acatech, 2015).

2.1.3. The policy approach of the main industrial powers

One of the characteristics of the ‘fourth industrial revolution’ is the fact that, differently from previous techno-economic shifts, the present one is being announced *a priori* and not recognized *ex-post* (Muscio and Ciffolilli, 2017); this aspect gives an important opportunity for the main political, economic and social forces to organize systematically (Schwab, 2016). In order to face the multiple challenges lying behind these transformations, governments started to develop industrial plans based on strategic PPPs, aimed at supporting manufacturing and accelerating the adoption of ‘advanced manufacturing’ technologies.

In fact, the pillar of the U.S. strategy for ‘advanced manufacturing[45]’ is represented by the constitution of a National Network of Manufacturing Innovation Institutes (NNMI), working as PPPs, with the purpose to support “regional ecosystems in advanced manufacturing technologies” (NNMI, 2016, p.2). A Manufacturing Innovation Institute is defined as “a public-private partnership of companies, academia, State and local governments, and federal agencies that co-invest in developing world-leading technologies and capabilities. Each institute creates the necessary focus and provides the state-of-the-art facilities needed to allow collaborative, mostly pre-competitive development of promising technologies. An institute provides

[45] See the “Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing” issued in 2012 under the Obama Presidency.

workforce education and training in advanced manufacturing (...) and promotes the creation of a stable and sustainable innovation ecosystem for advanced manufacturing[46]" (NNMI, 2016, p.4).

In line with the U.S. industrial strategy, the European Commission started pursuing actions to implement strategic PPPs[47] in this direction. Germany has been one of the leaders of this transition (Acatech, 2011) promoting the High Tech Strategy, through the constitution of the "Platforme Industrie 4.0[48]".

Taking inspiration from the German initiative, the French government has recently organized the 'Alliance Industrie du Future' (Alliance du Future, 2016), presenting its own vision relative to the "Nouvelle France Industrielle" (NFI, 2016), based on the "Projects Industrie du Future[49]". In 2012, the UK has announced the English strategy focused on the High Value Manufacturing (HVM) (TSB, 2012), with the support of the HVM Catapult, which has the mission to "bridging the gap between business and academia,

[46] The pilot manufacturing innovation institute was established in 2012, with the Department of Defense (DoD) as the leading funding agency. Supported by the lead funding agency authorities of the DoD and of the Department of Energy (DOE), further institutes were realized in 2014 and in 2015: in December 2014 the Congress issued the Revitalize American Manufacturing and Innovation (RAMI) Act, suggesting the Secretary of Commerce and the Administration to create a NNMI Program. By the August 2015, with the creation of the seventh manufacturing innovation institute, a total amount of over $500 million was allocated, generating an amount of over $1 billion in matching commitments of non-federal funds. Today, there are currently nine Manufacturing Innovation Institutes: America makes, Digital Manufacturing and Design Innovation Institute, LIFT, the Lightweight Innovations for Tomorrow, PowerAmerica, IACMI (Institute of Advanced Composites Manufacturing Innovation), AIM Photonics, NextFlex, Revolutionary Fibers and Textiles and the Manufacturing Innovation Institute on Smart Manufacturing.

[47] There are some main examples in this direction: the action from 2008 to 2014, focused on the smart use of ICT and the integration of SMEs into the digital value chains; the Horizon 2020 research programme, between 2015-2020; the Energy-efficient Buildings (EeB), a PPP between the European Commission and the private sector, aimed at creating and integrating technologies and solutions enabling to reduce energy consumption and GHG emissions; Factories of the Future (FoF), which initiated under the Seventh Framework Programme and continued under Horizon 2020, a PPP aimed at supporting the EU manufacturing enterprises, in particular SMEs, to develop key enabling technologies of a broad range of sectors, in order to face the global competition; the SPIRE, a PPP between the European Commission together with companies of eight sectors, chemicals, cement, ceramics, minerals, steel, non-ferrous metals, industrial water and process engineering; I4MS, launched in 2013 and aimed at promoting leading edge technologies in robotics and cloud based simulation services, laser based applications and intelligent sensor-based equipment; Smart Anything Everywhere, a set of innovation initiatives supporting SMEs in digital value creation; other PPPs like the European Green Vehicles Initiative (EGVI), Photonics, the High Performance Computing, euRobotics, Big Data Value, 5G Infrastructure, Vanguard Initiative, a multiregional initiative for new growth, which aims at supporting European regions to foster entrepreneurial innovation and industrial renovation.

[48] The Platform brings together businesses, the government, the scientific community, the employ-representation bodies in order to manage the process of digital transformation of the industry, focusing on four main areas of intervention: making content recommendations, identifying the needed actions to facilitate businesses to integrate the new Industrie 4.0 approaches and technological developments into their business practices; mobilizing businesses, supporting enterprises, in particular SMEs to get involved in Industrie 4.0, taking inspiration from the businesses which are already on the frontier; providing single-source support, being the central point of contact for businesses which are interested in implementing programmes and projects in the area of Industrie 4.0, without incurring in duplications; promoting international networking, maintaining close relationships with strategic players outside Germany, in Japan, USA, France and China.

[49] The main priorities for the elaboration of these projects are: digitalization, virtualisation and IoT, robotics and augmented reality, additive manufacturing, monitoring and control, new materials, automation systems and energy efficiency systems.

helping to turn great ideas into reality, by providing access to world-class research and development facilities and expertise that would otherwise be out of reach for many businesses in the UK[50]".

In September 2016, Carlo Calenda, the Italian Ministry for Economic Development presented a National Plan for Industry 4.0, which is the result of the Final Report titled "Explorative research on 'Industry 4.0'. Which model for the Italian industrial system? Tools to favour the digitalization of the productive value chains" (own translation, X Commissione Permanente, 2016). The national Plan for 'Industry 4.0' is thought to be a possible answer to the need of a strategic industrial policy for the Italian country. The pillar of this industrial strategy is represented by the creation of a techno-economic "directing room", composed by public and private players: ministers, Universities, research centres, banks, the labour and entrepreneurial associations. The key guidelines of the Italian plan are mainly two: on one hand, the support though fiscal incentives on private investments finalized at 'Industry 4.0'; on the other hand, the development of the competences needed at all levels of the education system, through the creation of Competence Centres[51] and Digital Innovation Hubs. Moreover, additional guidelines concern, on one hand, 'enabling' infrastructures, adequate networks and inter-operability standards for the IoT; on the other hand, public tools, supporting big innovative investments and internationalization. Both strengths[52] and weaknesses[53] of this strategic plan[54] are highlighted (ADAPT-FIM CISL, 2016; Lombardi, 2017; Bacchetti and Zanardini, 2017), especially in light of the industrial strategies developed by the worldwide industrial powers. Paragraph (3.1.2.) will provide further details about this plan.

[50] Seven competence centres and seven Universities are involved with 1260 high qualified researchers, including engineers, scientists and technicians.

[51] The Competence Centres identified by the Government are the following: the University of Bologna, Politecnico di Milano, Politecnico di Torino, Politecnico di Bari, Scuola Superiore Sant'Anna in Pisa, the University of Veneto, and University of Federico II of Naples.

[52] Among the main strengths underlined there are the government decision's to avoid an old 'top-down' and 'picking the winner' approach to industrial policy supporting specific industrial sectors in favour of an explicit 'horizontal approach', based on the principle of 'technological neutrality'; the awareness that 'Industry 4.0' is not just a matter of the introduction of new technologies, but a revolution in the entire economic and social system, combining short term (fiscal incentives) with medium-long run measures (competences and infrastructures) (Bacchetti and Zanardini, 2017); the intention to institutionalize Competence Centres and Digital Innovation Hubs, with different functions assuming to facilitate the close cooperation between Universities, key private players, research centres and start-ups; the intention to support the educational system, through local laboratories, digital curriculum, master and bachelor degree courses, PhD in partnerships with industrial players, focused on Industry 4.0. at all levels (ADAPT-FIM CISL, 2016).

[53] Among the main critical aspects highlighted (Bacchetti and Zanardini, 2017; ADAPT-FIM CISL, 2016; Lombardi, 2017) there are the delay of 5-6 years in the introduction of the plan, in comparison to Germany and to the U.S. with evident implications in terms of timing; the lack of a proper analysis concerning the impact of Industry 4.0 on labour in terms of the need to adapt professional competencies and skills as well as the lack of a clear discussion on the technological transfer of research activities; the choice to institutionalise a 'directing room' characterized by the presence of numerous strategic players which doesn't seem to be an efficient choice in terms of coordination capacity; the lack of clarity on how the multiplier effect of the public investments is effectively built up.

[54] See also: http://channels.theinnovationgroup.it/digitaltransformation/2017/04/28/piano-nazionale-industria-4-0-tra-luci-e-ombre/

2.2. The need for a new approach in policy making during socio-technical transitions: the recent debate

The adoption of strategic PPPs as levers of industrial policy has not always been a priority of governments' industrial strategies[55]. In Europe, the Lisbon Agenda of 2000 signed the beginning of a new phase in the debate for effective industrial policies going towards this direction. The agenda[56] was born with the purpose to fill up the technological gap with the U.S., recognized as the new model to look at, through investments in R&D and support measures to innovation, in order to make the European Union, "the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion[57]".

The worldwide shock following the financial crisis of 2008[58] has revealed the complete inadequacy of liberal policies in assuring the stability of the economic system and the importance to put manufacturing at the centre of effective industrial policies[59]. As already mentioned, taking inspiration from the U.S., which today are one of the most active countries supporting a 'new manufacturing oriented view' of policy making (PCAST, 2011; 2014), the European Commission has stressed the need to focus on post-crisis growth and modernization, calling the European countries to recognize the central importance of industry for creating jobs and growth in order to reach smart, sustainable and inclusive growth[60] (European Commission, 2014).

[55] Bianchi and Labory (2011) and Owen (2012) provide an interesting overview on the evolution of the industrial policies debate after the Second World War: the period 1950s-1980s was characterized by a strong governmental interventionism mainly directed to the need to reconstruct the economy and, in a second phase, by the support of few large firms and agglomerations according to a 'picking the winner' approach; however, as a consequence of the government failures, during the period 1980s-2000, the idea of the general inefficacy of the investments of the government in the industry led to a general disappointment related to interventionism, leading many countries to reconsider 'liberal' policies based on a greater reliance on the capacity of markets to 'self regulate'.

[56] The Lisbon Strategy envisaged six main measures (Bianchi and Labory, 2011): the e-Europe action plan, aimed at developing an information society based on the use of the internet in government and public services and to stimulate competition in telecommunication; the creation of the European Area of Research and Innovation, finalized at improving the coordination between innovative activities within Europe, at supporting the relationships between business and academia, at promoting researchers' mobility and creating a European patent system; the promotion of innovation through the support to SMEs and firm creation; the completion of the internal market, in financial and other services and the promotion of efficient and integrated financial markets with particular attention to SMEs' access to financial capital; the coordination of macro-economic policies.

[57] See: https://portal.cor.europa.eu/europe2020/Profiles/Pages/TheLisbonStrategyinshort.aspx

[58] The 2008 financial crisis started from the collapse of the financial and housing markets in the U.S. and ended with a worldwide crisis in the real economy, with a negative effect on expectations and a stagnation of the demand growth. Three main reasons determined the bubble burst (Bianchi and Labory, 2011): the abundant liquidity in world capital markets fed by the large payments imbalances between countries; the expansionary monetary policy pursued in the U.S. since 2000, which kept interest rates low; the credit boom leading to an unsustainable leverage (housing market); financial innovation, like securitization and derivative contracts easing the growth in financial intermediation.

[59] Andreoni and Gregory (2013) explain three main reasons for these priorities: it's a crucial source of high quality employment, it's fundamental to keep the trade balance in equilibrium and it's essential for a high productivity and scope for innovation. In this context, Pisano and Shih (2009) underline the negative consequences of the globalization process: sourcing decisions, lack of investments in manufacturing capabilities and the loss of the ability to innovate and to compete at a global level (Pisano and Shih, 2009). The authors point out that only by supporting the 'industrial commons' and promoting the collaboration between business and academia, the world's economy can regain competitive advantage

[60] The following targets were set to be reached within 2020: 75% of the population aged 20-64 should be employed; 3% of the EU's GDP should be invested in R&D; the "20/20/20" climate/energy targets should be met; the share of early school leavers should be under 10% and at least 40% of the younger generation should have a tertiary degree; 20 million less people should be at risk of poverty.

In order to face these priorities, today both academics and policy makers recognize that neither a government-led strategy, limiting the interventions of the government to 'fixing market failures', nor a market-led strategy, based on the liberal concept of 'self regulating' market, are able to prevent the economic system from malfunctioning: a new theoretical paradigm to policy making is emerging based on the so-called 'mission-oriented approach' to policy making (Rodrik, 2004; Warwick, 2013; Mazzucato 2014; Mazzucato and Perez, 2014; Mazzucato and Jacobs, 2016), which has recently been adopted as source of inspiration by the European Commission in the elaboration of the 9th Framework Programme for Research and Innovation (European Commission, 2018). "A recognition of the need for government policy to "transform", to be catalytic, and to create and shape markets, rather than merely fix them, helps to reframe the key questions of economic policy from static ones that worry about crowding out and picking winners to more dynamic ones that are constructive in forming the types of public-private interactions that can create new innovation and industrial landscapes" (Forum, 2015, p. 125).

The following paragraphs are dedicated at summarizing the main rationales of policy making in economic theory, focusing on their limitations in the present scenario and on the inspirational principles which can be derived from a 'mission-oriented' approach (Mazzucato, 2014).

2.2.1. Rationales of policy making in economic theory: from the market failure approach to the complexity theory

The market failure approach

The market failure approach is based on three main assumptions: 'rational behaviour[61]', the linear concept of innovation[62] and a specific concept of knowledge[63].

An economic system should be evaluated looking at its distance from the point of equilibrium; if one of these assumptions fails, governments should intervene to correct the non-desired externalities, asymmetries in information, inefficient market structure and eliminate the barriers to entry, in order for

[61] Assuming perfect rationality, economic agents are able to maximize their expected utility and the economic system to reach a Pareto optimal; Pareto optimality, or Pareto efficiency, is a state of allocation of resources in which it is impossible to make any one individual better off without making at least one individual worse off.

[62] According to the 'linear' concept approach (Chaminade and Edquist, 2006), innovation starts with basic research, followed by applied research and development, ending with production and diffusion, in a fixed sequence of phases (Kline and Rosenberg, 1986). In this framework, the way through which the results of the research activity are transformed into products and processes is a 'black box' (Kline and Rosenberg, 1986) in which innovation is the result of the generation of codified, generic and accessible knowledge, which is easily adaptable to the firms' specific conditions (Chaminade and Edquist, 2010).

[63] Both according to Nelson (1959) and Arrow (1962), knowledge is characterized by three main properties: uncertainty, indivisibility and inappropriability. Uncertainty refers to the fact that it is impossible to fully know the outcomes of the research process and the risks related to it; indivisibility means that in order for new knowledge to be created, a minimum investment must be made; inappropriability refers to the impossibility to fully appropriate the benefits deriving from the inventions; since the research process generates externalities, the incentives for firms are less than in the case firms could appropriate of all the benefits. According to Nelson (1959), since basic research is an uncertain process and characterized by external economies, he suggests that the direct public intervention would be able to overcome the private underinvestment in research. Arrow (1962) maintains that inappropriability, uncertainty and indivisibility imply a mismatch between public and private returns to innovation, meaning that there will be an underinvestment in innovation, with respect to the social optimum.

markets to be able to reach the equilibrium (Chaminade and Edquist, 2006). This framework derives from the idea that markets should be considered as a privileged standing, so that any non market supplement to market organization should be considered as 'second best solution', justified because market fails in some sense (Foray et al, 2009). Drawing on Swann (2010), the literature analyzes three main cases[64] in which market failures occur: economies of scale and scope[65], asymmetric information[66] and externalities which may be both negative and positive[67].

There are three prevalent approaches proposed in the literature as ways through which market failures may be adjusted (Swann, 2009): the 'Samuelson approach' which maintains that the State guarantees that innovative activities take place, through direct public expenditure in R&D and in technological and scientific infrastructures, which are socially convenient but privately unprofitable; the 'Pigou approach' which implies that the government offers subsidies, tax credits and grants for activities which generate positive externalities and imposes taxes and fees for activities generating negative externalities; the 'Lindhal approach', based on the 'commoditisation' of the externalities deriving from the R&D activities: the provider of positive externalities, the innovator for example, will receive from the beneficiaries a royalty for taking advantage of the benefits received from the intellectual property rights. This intervention gives an incentive, in terms of temporary monopoly, to the innovator for his inventions, producing an increase in the revenues of

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[64] Whereas economies of scale, information asymmetries and externalities are considered the traditional market failures in mainstream economics, the neoclassical theory has come to identify a fourth source of market failure, which is in some sense close to a more 'evolutionary' framework. Standard game theory recognizes that a market failure may occur when users get locked-in to an old standard, even if it would be joint interest to change to a different solution: the intervention of the government is needed because the economic players are not able to coordinate their actions in order to move to the desirable alternative (Swann, 2010).

[65] First of all, economies of scale and scope are not a failure 'per se', but because of the market which fails to manage these economies. There are two main reasons for which economies of scale and scope may lead to a market failure. The first is related to the case in which economies of scale and scope derive from fixed costs of production. In this case, the firm will have to fix a price which is not equal to the marginal costs, but at a higher price, in order to recover the fixed costs. As a result, some consumers will be priced out of the market, since they will not be willing to pay at a price which is higher than the marginal cost of production and they will not buy the products. The second reason is related to the possibility that economies of scale may lead to monopolies on the market; in this case, the large scale producer, that will have lower average costs than any other smaller scale producer, will exclude the smaller scale competitor from the market; this is because the monopolists will not translate the lower average costs into lower average prices, but will increase them as much as they can. In this case the monopolization of the market is in itself a form of market failure. Since the elimination of economies of scale and scope is not reasonable, since they are beneficial in the market, the solution is to regulate monopolies, preventing them to fix prices which are too high, or place them in public ownership, whose purpose is typically not to maximize profits, but to increase public and social welfare.

[66] Asymmetric information is another source of market failure, which is well described in the often cited example of the second-hand car market. Asymmetric information about the effective quality of the car will bring disadvantages both to the buyer and the seller: to the buyer, since he is not able to know whether he is buying the car at the right price, due to the lack of information about the quality of the car; to the seller, since this asymmetric information can lead the buyer to give up from buying, inducing also the seller of good quality cars to withdraw them from the market, not being able to achieve acceptable prices. As a consequence, the average quality of the second-hand market will decline, generating a market failure. In order to prevent this failure, some main solutions may be adopted: the seller may build up a reputation for his reliability, offering some guarantees to the buyer; there may be some independent agencies providing information of the conditions and value of the second hand car; sellers may use standards and certification to demonstrate that the products meet some standards and may justify the payment of a premium price.

[67] In case of negative externalities, the market fails to reach the equilibrium, because certain activities which are privately profitable are instead socially costly: in this case the market fails because activities causing negative externalities take place, while they should not. On the other hand, in case of positive externalities, markets fail to reach the equilibrium, since activities which ideally should take place, do not.

the new knowledge produced. At the same time, those suffering from negative externalities may ask for some sort of compensation[68].

The neoclassical approach soon came to be criticized, both from a theoretical and a practical point of view. From a practical point of view, it was soon recognized to be too vague and abstract to provide much guidance for policy makers (Chaminade and Edquist, 2010); limiting the possible intervention of the government to the occurrence of market failures, this approach is unable to provide suggestions concerning the optimal level of investment and on the specific area of intervention, without taking into account the possibility that governmental intervention could be beneficial, regardless of specific market failures (Nelson, 2004). These limitations laid the foundation for the development of an alternative theory to industrial policies: the evolutionary approach to innovation studies that will be described in the following section.

The evolutionary approach: the systems of innovation approach

Evolutionary economists maintain the idea that innovation and technical change are the main forces shaping economic evolution. Joseph Schumpeter is one of the pioneers of the evolutionary approach to long-run economic development. Schumpeter's works are considered the starting point for the development of a more formalized model of economic evolution elaborated by Richard Nelson and Sidney Winter, and contained in their book of 1982, "An Evolutionary Theory of Economic Change". Nelson and Winter (1982) argued that it was necessary to try to open up the black box of the production function, incapable of explaining technical change; on the basis of previous attempts (Alchian, 1950, Penrose, 1959), the authors provided a complete theoretical framework of contemporary evolutionary economics, introducing the notion of *organizational routines* as the new units of analysis of social evolution. According to the authors, innovation was highly dependent on firm-specific capabilities, strongly rooted in organizational routines, the key determinants for firms' survival in the process of competitive selection.

The evolutionary framework builds upon several limitations of the neoclassical theory: the idea of economic agents as "optimizing" players[69]; the "linear model of innovation[70]"; the assumption of individual economic agents acting in isolation[71]; the "institutional complexity of modern capitalist economies[72]"

[68] The neoclassical theory has evolved in different extensions, but maintaining the basic rationale of analysis. Two further extensions are the strategic trade policy and the endogenous growth theory, or new growth theory (Romer, 1986). The strategic trade policy provides a rationale for supporting the domestic firms to acquire a strategic position in the market against foreign competitors, through the provision of subsidies. Supposing there are two countries, "X" and "Y", selling to a third country "Z" not producing the product, if one of the two exporting countries applies a subsidy in "Z", then, if "Y" does not intervene, "X" will enjoy of an overall increase in the welfare gain, through a rent shifting policies: oligopoly will shift from "Y" to "X". The endogenous growth theory or "new growth theory" was elaborated by Romer (1986) in response to a limitation of the standard neoclassical theory assuming that the rate of growth of a country is exogenously fixed. On the contrary, public policies are able to impact in the long run economic development, raising the rate of growth of a country, providing subsidies on research and development activities and funding education; through the increase in the incentives to innovate, the overall rate of growth will increase in the long run.

[69] Economic players are not homogenous optimizing innovators but heterogeneous and unbounded rational behaving according to their specific capabilities (Nelson and Winter, 1982; Metcalfe, 1995)

[70] The innovation process is better described by a 'chain-linked model' (Kline and Rosenberg, 1986) where the outcome is uncertain and is the result of an interaction process occurring both inside and outside the firm; there are many channels from invention to wealth creation, in which different players and institutions play a crucial role (Swann, 2010).

[71] Agents do not act in isolation but interact with both private and public players, which can be organizations and institutions (Edquist, 2004).

(Nelson, 2004, p. 9). Metcalfe (2005) underlines that a framework based on perfect competition is incompatible with the features of innovation processes; in fact, market failures do not provide precise implications in terms of policy, since they are "vital elements in the evolutionary process", due to the presence of externalities, uncertainty and increasing return[73] (Marzucchi, 2010). "A world in which innovation, or indeed any change of human knowing, is absent, can serve only as a distorting mirror in which to reflect the innovation policy problem" (Dodgson et al., 2010, p. 8). "Nevertheless, this literature has not addressed institutional issues, it has a very narrow concept of uncertainty, it has no adequate theory of the creation of technological knowledge and technological interdependence among firms, and it has no real analysis of the role of government. In addressing these core features of reality, the systems approach takes us, for all its possible limitations, into a more promising arena for policy analysis" (Smith, 2000, p.75).

The development of an evolutionary approach to innovation studies (Nelson and Winter, 1982) paved the way to the flourishing of studies showing *the cumulative, path dependent* (Dosi, 1988), and *systemic* character (Freeman, 1987; Lundvall, 1988; 1992) of innovation processes. According to a *systemic* view of innovation, the focus shifts "from artifacts to systems, from individual organizations to networks of organizations" (Geels, 2004, p. 898) with a close relation to the territorial dimension. Studies concerning *systems of innovation* developed at different levels: *national*[74], *regional*[75] and *sectoral*[76].

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[72] The idea that under specific conditions the operation of a pure market yields a Pareto optimal is potentially biased for several reasons: first of all, because it identifies the pure market organization as the best structure; supplements to market organization are necessarily second best solutions, only because markets fail in some sense; second, it is necessary to recognize that pure market organization always fails, at least to some extent; third, as there is no such thing like a perfect market, there is no such thing like a pure market, meaning that markets are always supported by non market mechanisms, which are strictly related to the institutional setting. In the evolutionary approach, the institutional evolution is a crucial part of the dynamic processes of economic change, because the institutional evolution goes along with the technological evolution; in this context, policy making is seen as a 'continuing process'.

[73] This is true for several reasons: first, because a firm might be unable to exploit effectively knowledge from other firms, due to firms' heterogeneity in skills and competence; second, informative asymmetries and uncertainty are not obstacles but preconditions for new ideas to emerge; third, the assumption of perfect competition is incompatible with indivisibility and increasing returns: when firms innovate, they have to face a minimum scale of exploitation that decreases as the scale of exploitation grows.

[74] At the national level, Freeman (1987), Nelson (1993) and Lundvall (1988, 1992), are considered the pioneers of the so-called national system of innovation approach. According to Lundvall (1992, p. 1), "the most important resource in the modern economy is knowledge and the most important process is learning (…) a socially embedded process which cannot be understood without taking into consideration its institutional and cultural context". The national system of innovation approach developed on the basis of the work of Friedrich List of 1984, "National System of Political Economy", where he suggested the need of a broad range of policies aimed at accelerating industrialization and economic growth and strictly concerned with learning about new technologies and their application. He claimed that the industry should be closely related to the formal institutions of science and education. Later on, different definitions of national systems of innovation were provided: "network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies" (Freeman, 1987, p. 1); "(…) the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge ... and are either located within or rooted inside the borders of a nation state" (Lundvall, 1992, p. 12). In Freeman (1995) it is shown that the differences in national institutions influence the relative rates of technical change and of economic growth in different countries. Balzat and Hanusch (2003) consider national innovation systems as "historically grown subsystem of the national economy" (Balzat and Hanusch, 2003, p.2), where institutions are crucial for the stimulation of innovative activities. The need to look at institutions not as "a source of institutional drag", which contribute to the inertia of the system, but as crucial sources for technical and economic change, is also underlined in Johnson (1992).

[75] The region has been adopted as the unit of analysis of the systemic approach, as a result of the recognition of profound differences between regions within the same country (Cooke et al., 1997; Cooke, 1998). Originally, the concept of regional innovation system was associated to a dynamic region where the strong institutional infrastructure embedded in the territory and closely linked to firms and organizations involved in interactive learning processes, was

In order to analyze industrial transformations characterized by complex and uncertain processes, Geels (2002; 2004; 2005; 2010) suggests the transition from sectoral to *socio-technical systems*, which are defined as "the linkages between elements necessary to fulfill societal functions (e.g. transport, communication, nutrition)" (Geels, 2004, p. 900). *Socio-technical systems* are the outcome of the activities of human players and thus include artefacts, knowledge, capital, labour and cultural meaning. In this context, not only firms and industries are important but also other groups are relevant, as users, societal groups, public authorities and research institutes[77]. In Geels' perspective, the technical and the social aspects of human condition are deeply integrated and the co-evolving of technology and society acquires fundamental importance.

In a stylized representation provided by Geels (2002), reported in Figure 4, systems of innovation are the result of the interaction of dynamics operating at multiple levels; novelties originate in niches in which different technical forms compete together; this phase is characterized by the breakthrough of the new technology, which develops and diffuse within the established regime: a new technological trajectory develops; the substitution of the old with the new technology implies changes at a broader scale of the socio-technical regime. The fact that socio technical systems do not consider only new technologies but also deep transformation in markets, user practices, policy and cultural meaning is understood in the context of a multi-level perspective, an adequate framework taking into account the complexity of the multiple dimensions involved: innovation is a multi-facet process which implies transformations in products, processes, markets and organizations, which requires a multidisciplinary approach between cultural studies, political economy, economic sociology, and consumer studies to be analyzed (Geels, 2010; Lombardi, 2010).

As in the case of the transitions towards new technological paradigms, also the impact of technological revolutions is far beyond industries, implying changes at different levels of the economic and social system (Perez, 2010). In a multi-layered perspective, a techno-economic paradigm is the result of the convergence of a complex set of factors interacting in the economic, social, cultural and institutional

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the key element supporting innovation and the overall regional economic performance (Uyarra, 2011). According to Asheim and Isaksen (2002, p. 83), regional innovation systems may be defined as "places where close inter-firm communications, social structures, and the institutional environment may stimulate socially and territorially embedded collective learning and continuous innovation".

[76] Moving from the regional to the sectoral level, there are different approaches describing the systemic nature of innovation: sectoral systems of innovation (Breschi and Malerba, 1997; Malerba, 2009), technological systems (Carlsson and Stankiewicz, 1991) and large technical systems (Hughes, 1988). A sectoral system of innovation is defined as "a system (group) of firms active in developing and making a sector's products and in generating and utilizing a sector's technologies" (Breschi and Malerba, 1997, p. 131). The authors identify two main ways in which firms interact: cooperative relations in artifact-technology development and competitive relations in innovative market activities. Carlsson and Stankiewicz (1991, p. 111) define technological systems as "(...) networks of agents interacting in a specific technology area under a particular institutional infrastructure to generate, diffuse and utilize technology". They focus the attention on the role of knowledge and learning rather than on goods and services. In the context of a complex and 'evolving' framework, the learning patterns of firms populating a technological system are determined by a variety and generation mechanisms, based on organizational routines (Nelson and Winter, 1982); moreover, they evolve through a selection process, determined by the market forces; an organization and environmental analysis of their dynamic capabilities is useful for the analysis of how firms interact in technological systems (Antonelli and Pegoretti, 2008). Finally, large technical systems (LTS) (Hughes and Mayntz, 1988) represent technological infrastructures involving physical artifacts, natural resources, scientific elements and legislative artifacts.

[77] There are two main characteristics of socio-technical systems: on one hand users have to integrate new technologies in their practices, organizations and routines, activating learning and adjustments mechanisms; on the other, new technologies have to be adapted to the existing routines and contexts.

dimension (Perez, 2001). "Thus, on a first approximation a technological revolution can be defined as a set of interrelated radical breakthroughs, forming a major constellation of interdependent technologies; a cluster of clusters or a system of systems (Perez, 2010, p. 189)". "Thus, a technological revolution can be seen more generally as a major upheaval of the wealth-creating potential of the economy, opening a vast innovation opportunity space and providing a new set of associated generic technologies, infrastructures and organisational principles that can significantly increase the efficiency and effectiveness of all industries and activities" (Perez, 2010, p.190).

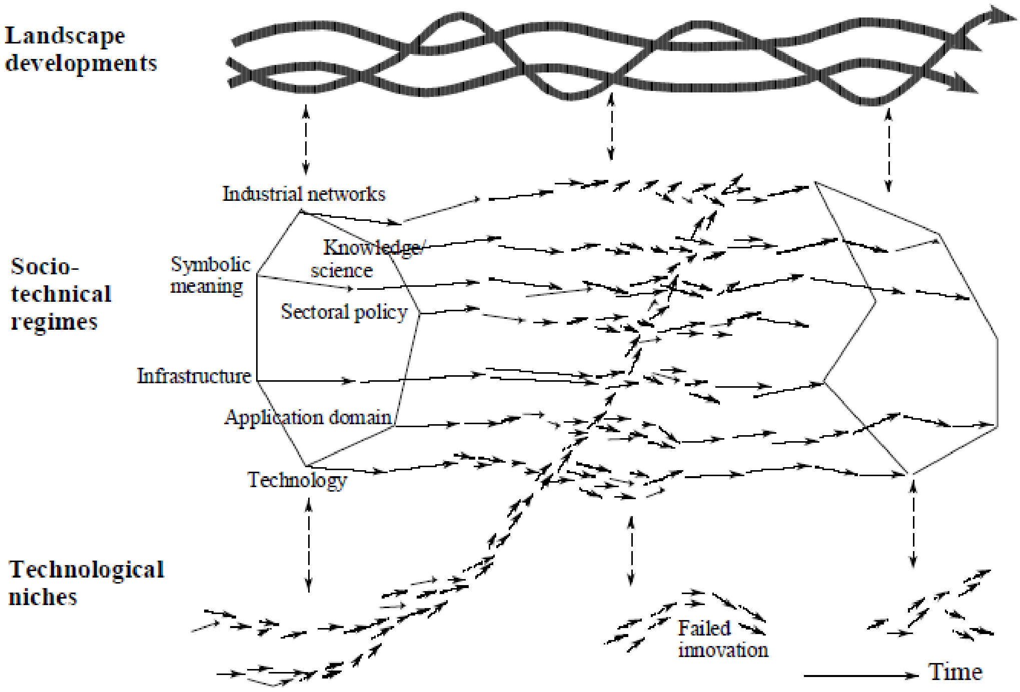
Perez (2010) underlines two main elements which distinguish a technological revolution from a random collection of technology systems: the strong interconnectedness and interdependence of the participating systems in their technologies and markets; the capacity to transform profoundly the rest of the economy (and society). This latter element qualifies the meaning of techno-economic paradigm, that is, "a best practice model for the most effective ways of using the new technologies within and beyond new industries" (Perez, 2010, p. 189). "Each paradigm provides a new set of "common sense" principles which serve to guide the decision-making of entrepreneurs, innovators, managers, administrators, engineers and investors towards the greatest efficiency and efficacy in both old and new activities" (Perez, 2001, p. 117).

Through interrelation changes operating at different levels, new technological paradigms consolidate in new social-technical regimes defined as "stable configurations of institutions, techniques and artefacts, as well as rules, practices and networks that determine the 'normal' development and use of technologies" (Smith et al., 2005, p. 1493). However the stabilization process is often preceded by a turbulent phase characterized by deep discontinuities in the techno-economic paradigm and knowledge asymmetries between the agents involved at different levels: the major incumbent industries are replaced by new ones, the established technologies become obsolete, the working and management skills become outdated and inefficient; great imbalances and tensions occur, including financial bubbles and collapse[78] (Perez, 2009). It is only when the overall institutional framework reaches its full transformation that the full potential of each revolution is exploited (Perez, 2010; Mazzucato and Perez, 2014).

In fact, during this phase of transition, it may be that *positive feedbacks* that enable the shift to new socio-technical systems may turn out to be *negative feedbacks*, due to lock-in effects, that hinder the transformation of the existing system and the consolidation of the new one (Lombardi, 2010). One of the possible causes for this failure may be neglecting the role of policies in guiding the direction of techno-economic shifts. "Ignoring the potent role and influence of technical and institutional change in shaping the economy reduces the analytic capacity of economics. Incorporating them in a historically dynamic approach is an important task in order to enhance the explanatory and predictive power of economic science" (Perez, 2010, p. 201).

[78] Perez (2009) argues that a 'Major Technology Bubble' occurs not as an accidental event but as assimilation of the technological revolution.

Figure 4: A dynamic multi-level perspective on technological transitions



Source: Geels, 2002

The complexity theory

The development of the complexity theory, starting from the Nineties, confirms the increasing importance recognized by the economists of innovation as a complex phenomenon, resulting from the interaction of multiple factors at different levels. Some brief assumptions of the complexity theory are worth to be mentioned. In 1987 a group of economists and physics organized a workshop at the Santa Fe Institute which was aimed at finding ways to enrich economic theory, starting from the limitations recognized in the neoclassical theory, which they identified with the General Equilibrium Theory[79] (GET). The meeting in 1987 generated the so called Santa Fe Perspective and has been considered the starting point for the elaboration of notion of economies as Complex Adaptive Systems[80] (CASs). As opposed to the GET, complex adaptive economies are characterized by "dispersed interaction, no global controller, cross-cutting hierarchical organizations, continual adaptation and out-of-equilibrium dynamics" (Fontana, 2010, p.586).

[79] The GET, assuming agents endowed with rational expectations, complete markets for all commodities at any time, equilibrium to be reached as tatônnement and equilibrium dynamics captured by difference or differential equations, was considered unable to provide "(...) a unique pattern of dynamic behaviour" (Arthur, 1988 in Fontana, 2010).

[80] There are five main features of CASs identified: first, the consistency of complex adaptive economies in many morphologically diverse parts; second, the fact that CASs exhibit a variety of nonlinear dynamics; third, the fact that CASs maintain themselves out of equilibrium; fourth, the fact that complex systems respond adaptively to change in ways that tend to increase their probability of persisting; fifth, that complex systems are characterized by irreversible histories, for which each event is the product of individual actions in a given institutional setting in a precise time and space (Fontana, 2010, p. 593).

In recent years, the complexity approach has become increasingly influential in different fields related to social science research, including theories of technological adoption and diffusion and models explaining innovation processes. According to Arthur (2009), economics evolves continuously thanks to the creation of novel combinations, the new markets, the new forms of industrial reorganization that contains a force of Schumpeterian 'creative destruction', destroying the old systems and creating a new one. For this reason, it needs to be analyzed from a dynamic and not from a static point of view. "Economics itself is beginning to respond to these changes and reflect that the object it studies is not at equilibrium but an evolving complex system whose elements, consumers, investors, firms, governing authorities react to patterns these elements create" (Arthur, 2009, p. 211).

The adoption of the complexity theory in economics generated many attempts to model systems as complex systems characterized by the interaction of multiple elements in a multilayered framework[81] (Frenken, 2006; Hirooka, 2006; Nightingale, 1998; Ozman, 2010).

Meaningful results in this context are provided in Pyka and Scharnhorst (2009), an attempt to link together the 'network' and the 'innovation' perspectives, deepening the bodies of knowledge on networks in economics, social sciences and statistical physics. In this volume, an interesting contribution is provided in Chapter Four by Beckenbach et al. concerning the "Evolution and Dynamics of Networks in 'Regional Innovation Systems", which investigates whether the agents in RISs innovate in a collaborative way, through a simulation with an agent-based model. The results of the study show the emerging of patterns concerning the frequency of the different modes of action and the dynamics on three different layers: political (legal), geographical, and cultural attributes influencing the interaction of the agents, additional institutional structures that are important for the agents creating novelties, by imitation or innovative behaviour, agents actually willing to cooperate for the implementation of innovations. The authors found different patterns on the meso level, including weak development of cooperative innovation at a low level, stable sales cooperation at a medium level and growing trust relations at a high level[82].

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[81] Frenken (2006) has developed a complex system approach to technological evolution through the adoption of the NK model. Hirooka (2006) provides a theoretical contribution which examines the nature of logistic complexity in a mathematical context, discovering that innovation systems are complex systems characterized by various fractals and by self-organization mechanisms. Nightingale (1998) shows how the linear model fails in describing how scientific knowledge is used in innovation, since it is unable to take into account the key role of embodied tacit knowledge in technical change; from this point of view, scientific knowledge cannot be abstracted successfully from the social context. Ozman (2009) provides a survey of the literature including studies in which innovation is a complex process characterized by the interaction of many players taking place on networks among firms. The analysis of the evolution of networks makes it possible to verify how economic outcomes are influenced by the relationships between the different players; confirming Teece's (1986) results, complex products and weak reusability of knowledge result in specialized firms with intensive interactions between them.

[82] The interaction between players in RISs maybe captured also through the adoption of Social Network Analysis (SNA) techniques. An attempt in this direction has been provided by Cantner et al. (2010), who applies SNA to the analysis of three different RISs (Northern Hesse, Jena, Alpes-Maritimes), focusing in particular on the differences in the ways in which innovating players within a region's boundaries engage in systemic forms of interaction, collaboration and knowledge exchange and whether they depend on the differences in the knowledge base of the respective regions. They show that networks in these three regions differ widely and the size and complementarities of the regional knowledge base are relevant elements explaining these differences.

2.2.2. A mission-oriented approach to innovation policies in socio-technical transitions: some inspirational principles

The development of the 'systemic' and 'complex' approaches to innovation goes hand in hand with the increasing emphasis on innovation as an important source of economic prosperity (Fagerberg, 2015) and innovation policy as an effective tool able to reach a smart, sustainable and inclusive growth[83] (Mazzucato, 2015; Mazzucato, 2014a). These theories made relevant progresses towards a better comprehension of how innovation processes work, in the context of particular institutional settings.

However, whereas they may be useful in steady state scenarios when the economic system is in equilibrium, since they identify some situations that may be corrected, in the case systems are not in equilibrium, for example when there is a shift towards a new techno-economic paradigm, this framework is not able to properly address government intervention in order to fully exploit the potential inherent to it[84]. "Our view, however, is that having a national system of innovation, rich in horizontal as well as vertical networks, is not sufficient in itself. The State has a further role to play: to lead the process of industrial development, developing strategies for technological advance in priority areas" (Mazzucato, 2014, p. 69). "Rather than focusing on particular sectors - as in traditional industrial policy - mission-oriented policy focuses on problem-specific societal challenges, which many different sectors interact to solve. The focus on problems, and new types of collaborations between public and private players to solve them, creates the potential for greater spillovers than a sectoral approach. It was this approach that put a man on the moon, and lay behind the creation of the Internet and entire new sectors like biotechnology, nanotechnology, and the emerging green technology revolution. It is not enough to fix market and system failures: policy-makers need to be more future focused, creating and shaping new markets[85]".

The 'mission-oriented' approach to policy making builds on several limitations of the main-stream theory.

The first limitation concerns the idea that, once the market failure has been addressed, the market forces will automatically bring the economic system into equilibrium, towards a path of growth and development[86]. But markets which are left free to operate generally lack a common direction to follow and are never able to bring the system into a first best equilibrium, fixing usually at second best positions. A useful theoretical framework should be able not to decide whether it should be the market or the State to

[83] See also https://marianamazzucato.com/projects/mission-oriented-innovation-policy/

[84] Studies analyzing the advent of mass production and the IT revolutions reveal that innovations during these phases do not arise automatically as a result of market forces, but thanks to 'mission-oriented' policies investing in key technologies and supporting their diffusion throughout the economy (Perez, 2001; 2009). Mazzucato (2014) in her book "The Entrepreneurial State", describes how in the IT revolution, the fundamental role of the State has been to invest in new technologies like the internet, mainframes, wind and solar power and fuel cells, not just correcting 'failures' but leading strategically public and private players towards the creation of new markets and sectors.

[85] See Mariana Mazzucato website: http://marianamazzucato.com/projects/mission-oriented-innovation-policy/

[86] Many recent facts involving the Western capitalism confirm this: weak growth, financial instability, low investments and financialization, decrease of the quality level of the living standards, increase of inequality and environmental problems (Mazzucato and Jacobs, 2016). They can be understood just in relation to the wider institutional structure and social, legal and cultural conditions. As pointed out by Karl Polanyi in the "The Great Transformation", the concept of 'free market' is seen as theoretical construct of the economic theory, since empirical evidence and history have revealed how national capitalist market has been actually the result of public policy. "The road to the free market was opened and kept open by an enormous increase in continuous, centrally organized and controlled interventionism".

freely operate in order for the first best solution to be reached, but to inform how strategic decisions should be adopted in order to deal with the technical and societal challenges.

The second limitation concerns the static vs. dynamic evaluation of the role of the government for the implementation of innovation policies[87]. The static approach leads the government to intervene only within the confines of the boundaries set by the business practices of the prevailing techno-economic paradigm, conflicting with the possibility to contribute to the creation of radical new markets and sectors. However, economic development is an intrinsically dynamic process, so that if the possibility that the governmental intervention can create new markets is not taken into account, than the measurement of the impact of public measures may be biased[88].

The third limitation is related to the importance of organization and learning mechanisms in the way the public authorities manage changing transformations. The market failure approach justifies the intervention of the State only in specific cases, discouraging the public authority from acquiring the necessary knowledge capabilities, like for example the one related to IT which are necessary in order to manage change and to attract talented workers. A framework which considers the capability of the governments to create new markets and sectors needs to take into account a proper understanding of the learning and organizational mechanisms[89].

There are some interesting cases in the U.S. presented in Mazzucato (2014; 2014a) in which the State has been the leader promoter of 'mission-oriented' policies, showing that the market failure approach may not represent an adequate framework of analysis in socio-technical transitions: Defence Advanced Research Projects Agency[90] (DARPA), Small Business Innovation Research[91] (SBIR), the Orphan Drug Act

[87] The mainstream theory is based on a 'static' view of the government for which the evaluation of investments is the result of a cost-benefit analysis, based on the comparison between the benefits deriving from the governmental intervention and the costs related to the market failure and the implementation of the policy, including governmental failures.

[88] A 'dynamic' view of the State is line with a Keynesian concept of the State presented in his book "The end of laissez-faire", 1926, where the author says that "The important thing for Government is not to do things which individuals are doing already, and to do them a little better or a little worse; but to do those things which at present are not done at all" (in Mazzucato, 2014).

[89] This idea has been already developed by Keynes, in his analysis of the business cycle. According to Keynes, government investments were needed not just to stabilize the aggregate demand in case of low level of expenditure, but also to stimulate the 'animal spirits' of the private sector, which is characterized by a low propensity to risk. The support of mission oriented innovation policies able to drive a strong economic performance may be done also through the stimulation of good expectations about the future growth, that is necessary not only during periods of downturn but also in periods of prosperity in order to drive a strong economic performance (Mazzucato and Jacobs, 2016).

[90] DARPA has been established with the aim to support the technological superiority of the U.S. in different sectors; the key for understanding the source of success of DARPA is that the private sector works with the public sector in order to identify and pursue the most innovative paths. In fact, the agency funded the formation of computer science departments, start-up firms with research support, supported the semi conductor research and human interface research, following the early stages of the internet. The strategic vision developed by DARPA helped much the development of the computer industry in the 1960s and 1970s.

[91]The SBIR programme was born during the Reagan government in 1982, as a consortium between the Small Business Administration and different government agencies like the Department of Defence, the Department of Energy and the Environmental Protection Agency. This programme has been established with government agencies with large research budgets to support initiatives of small and for-profit firms, providing support to a number of highly innovative start-up firms. It provides more than $2 billion per year in direct support to high-tech firms, supporting the development of new enterprises and guiding the commercialization of many new technologies from the laboratory to the market.

(ODA)[92], the National Nanotechnology Initiative in the U.S. and Apple Inc[93]. These examples have in common the fact that the State shapes the markets in order to drive innovation, through a network of symbiotic PPPs acting strategically in risk seeking activities.

As mentioned, the mission-oriented approach to policy making has been recently adopted by the European Commission (2018) as framework of inspiration for the definition of future strategies in Research and Innovation. In this document, it is specified that the fundamental element of novelty in the shift from the mainstream approach concerns the possibility to integrate a 'top-down' vertical approach with a 'bottom-up' horizontal approach to policy making in a dynamic framework, not supporting single firms or sectors, but addressing societal problems to be solved (e.g. climate change, plastic-free ocean, citizen health and well-being). The definition of precise lines of strategies triggers the necessary cross-disciplinary, cross-sectoral and cross-actor innovation dynamics through multiple bottom-solutions, up to these challenges. Also Frenken (2017) has recently underlined that the government's main task is to define clear and manageable societal objectives guiding a temporary collation of players to develop bottom-up solutions. This approach to innovation policy, combining both top-down and bottom-up solutions is more adequate with respect to the mainstream theories: the latter are limited to trigger related diversification, while the former are able to stimulate unrelated diversification strategies leading to radical innovations.

"The right way of thinking of industrial policy is as a discovery process - one where firms and the government learn about underlying costs and opportunities and engage in strategic coordination. The traditional arguments against industrial policy lose much of their force when we view industrial policy in these terms (…) What is needed instead is a more flexible form of strategic collaboration between public and private sectors, designed to elicit information about objectives, distribute responsibilities for solutions, and evaluate outcomes as they appear" (Rodrik, 2004, pp. 19).

Rodrik (2014) suggests three main principles in order for PPPs to be effective: *embeddedness, discipline and accountability.* The concept of *embeddedness* emphasizes the need for a strategic collaboration between the public and the private sectors with the purpose of learning where the bottlenecks are and how best to pursue the opportunities emerging from this interaction[94]. The right way of thinking about it is as a process of discovery, by the government no less than the private sector, instead of a list of

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[92] In 1983, a year later the SBIR programme was implemented, the Orphan Drug Act (ODA) was issued with the purpose to facilitate small biotech firms, with tax incentives, R&D subsidies, drug approval, intellectual and marketing rights for products developed for treating rare conditions. These measures improved their technology platforms and upgraded the quality of their operations, becoming an important player in this industry. Orphan drugs played a very important role in leading the development of the biotech industry.

[93] Apple has been able to generate disruptive products thanks to the fundamental support of the government: all of the technologies behind the I-Phone have been directly funded by the government investments. Phone microchips were due to military and space programmes of the U.S., comprising the entire early market for disruptive technologies; cellular communication traces its origin back to radio telephony capabilities, developed through the 20th century, thanks to the support of the US military. The technologies underpinning the 'smart' applications of the internet were developed by DARPA, during the 1960 and 1970 and GPS technology was created by the U.S. military's NAVSTAR satellite programme, and the multi touch interface was first developed by the University of Delaware through the support of NSF and CIA grants.

[94] There are different institutional settings that are useful for this kind of strategic collaboration: deliberation councils, supplier development forums, search networks, regional collaborative innovation centres, investment advisory councils, sectoral round-tables, private-public venture funds, and so on.

specific policy instruments[95]. The idea of *discipline* refers to the need to adopt discipline devices against firms gaming the system; firms which do not respect the rules, will see their subsidies cut[96]. "As long as there remains fuzziness about objectives, targets, and results - which seems inevitable, in light of the nature of green industrial policies - firms will always try to make a case for continued subsidies - either before the programme agency or through political lobbying" (p. 487). According to the idea of *accountability*, public agencies must be transparent concerning their activities and the way through which they implement them, in order to keep public agencies honest and legitimize their activities; transparency may be respected through meetings with firms and industry groups, reports on activities and budgets, audits by independent experts. "The time has come for a serious rethinking of both the policies and the premises behind them. Understanding innovation as a driver of growth, employment and well being and recognising the essential role of the State in innovating, creating new markets, stimulating and living direction to innovation is the essential foundation for a strategic re-design. In order for there to be a real chance of success, growth policy must be innovation policy" (Mazzucato and Perez, 2014, p.24).

2.3. Research questions, data and methodologies

The broad literature review on the new emerging technological paradigm known as 'Industry 4.0' and on the new approaches to policy making in the current socio-technical transition (Perez, 2010; Geels, 2005; Mazzucato, 2014) suggest some main elements, leading to the definition of the research questions addressed in the present Thesis.

First of all, the analysis of the complex and fast changing technological processes which today are summarized in the term 'Industry 4.0' has shown that the industrial system is shifting towards a new technological paradigm (Perez, 2001; 2010), which has its linchpin in the CPS, implying deep techno-economic discontinuities (Perez, 2010) and systemic transformations at micro, meso and macro levels of analysis (Geels, 2005). This new technological paradigm (Perez, 2010) is characterized by the progressive integration between the physical and the cyber space, as a result of the combination of a number of KETs, both related to the 'software' and to the 'hardware' knowledge domains; this complete integration between the 'physical' and the 'cyber' world is generating a 'physical-digital Multiverse' (Lombardi, 2017), leading to radical new ways of conceiving products, production processes and business models (Acatech, 2011; 2013; GTAI, 2015; Deloitte, 2014; McKinsey, 2015; Roland Berger, 2011; 2014; 2015; World Economic Forum, 2015; Osservatorio Smart Manufacturing, 2015; Lombardi, 2017): products are becoming *multi-technology*, resulting from the integration of a wide range of different knowledge domains, from mechanics,

[95] In the traditional principal-agent model, no interaction between the public and the private sector is needed, since "the agency framework assumes the principals already have a very good idea of what needs to be done to achieve public goals, and all that needs to be done is to provide the agents (firms) with the right incentives to carry out the requisite investments" (p.484). However, it may be that the public actor does not have the appropriate knowledge for this strategic role, so that an adequate policy framework must take into account a significant amount of interaction between the public and the private sphere.

[96] In South Korea for example, firms not meeting their export targets saw their subsides be removed and in some cases also be subjected to aggressive taxes. In Western countries, the author suggests the need to introduce measures that are not firm specific but institutionalized, first of all by fixing ex ante the objectives of a programme, in order to be able to control whether the programme is working or not.

information technology and electronics to physics, mathematics and chemistry; production processes are gaining substantial advantages in terms of efficiency, flexibility and possibility to realize custom made solutions; businesses are more and more adopting a collaborative approach to innovation, developing digital ecosystems in a variety of contexts, from manufacturing, logistic and energy services to farming and health care (Acatech, 2015; Deloitte, 2014; Lombardi, 2017).

In order to manage the unprecedented challenges posed by this disruptive technological wave (Schwab, 2016), the recent debate on industrial policies (Forum, 2015) calls for the need to overcome the traditional opposition between the picking the winner/top-down approach and a laissez-fare/bottom-up vision (Mazzucato, 2014; Mazzucato and Jacobs, 2016, European Commission, 2018, Frenken, 2017): the former ends up by supporting few national 'champions' and the latter is based on the idea that markets are able to 'self regulate', with the possible risk of being stuck in technological lock-ins; given the systemic nature of these socio-economic changes, both approaches seem to be inadequate to face the current challenges. This trend is witnessed by the recent proliferation of strategic programmes developed by the main worldwide industrial powers, as "Advanced Manufacturing" in the U.S. and "Platforme Industrie 4.0" in Germany, aimed at stimulating the optimal use of the new technologies for all the industrial sectors (European Commission, 2015) and managing the transition towards high-value digitized products and processes (Acatech, 2013; PCAST, 2014; European Commission, 2015), through strategic PPPs.

The rationale of these industrial plans seem to be well explained by the mission-oriented approach to industrial policies (Mazzucato, 2014; Rodrik, 2004; Mazzucato and Jacobs, 2016) which overcomes the dualism between the 'State' and the 'market', recognizing to the public authority the responsibility of defining precise lines of strategies which are implemented through symbiotic PPPs (Rodrik, 2004); these are assumed to generate information spillovers between the economic agents, leading to a better performance of the innovation system and to an increase in economic growth (Lòpez, 2008; Link, 2006; Mazzucato, 2014; Rodrik, 2004; 2014). In this context, PPPs may represent potent levers of governments (Mazzucato, 2014; Rodrik, 2004; 2014; Robin and Schubert, 2013) able to activate those cross-level synergies between the different socio-economic players, which are recognized as essential conditions in order for socio-technical transitions to occur (Perez, 2001; 2009; 2010; Mazzucato and Perez, 2014; Lombardi and Macchi, 2012; Geels, 2005).

Therefore, the aim of the present Thesis is to understand how the strategic coordination between public and private players may be an opportunity for the definition of effective innovation policies in the current socio-technical shift.

In order to deal with this complex research objective, a multi-level perspective is adopted (Geels, 2002; 2004; 2005; 2010), using both quantitative and qualitative methodologies. In particular, the research is organized in two main steps: (i) the first step has the purpose to explore the relationship between a specific approach to innovation and technology policy and the level of innovative and technological performance in a NIS, focusing in particular on the level of diffusion of PPPs, taking into account the case of Italy (ii) the second step has the scope to deepen the role of a specific approach to innovation policy on technological development in the case of an institutional-led RIS, the Autonomous Province of Trento.

The following paragraphs (2.3.1. and 2.3.2) specify the research questions, the data and the empirical methodologies adopted for each step of the research.

2.3.1. The case of the Italian NIS: a quantitative analysis

In the literature on collaborative innovation (Hagedoorn et al., 2000; Belderbos et al. 2004, Veugelers and Cassiman, 2005; Fritsch and Lukas, 2001; Bayona et al. 2001, Miotti and Sachwald, 2003; Mowery et al., 1998; Caloghirou et al. 2003; Fontana et al. 2006, Lööf and Brostrom, 2008; Schartinger et al. 2002, Robin and Schubert, 2013, Schøtt and Jensen, 2016), it is now undisputed that the boundaries of the firms are becoming more and more 'fuzzy' (Tether, 2002) and that firms are increasingly looking for external knowledge and skills in order to complement their capabilities and widen the range of their technological options (De Faria et al. 2010). This is true especially in the current technological scenario characterized by an increasing hypercompetitive environment and the growing complexity of the knowledge base (Nieto and Santamaria, 2007). The awareness that innovation is less and less the result of isolated agents (Monjon and Waelbroeck, 2003), but the outcome of a collaborative process with other firms and institutions, especially Universities and public research centres, is today at the centre of governmental policies, as the analysis on the main governmental strategies on 'Industry 4.0' confirmed (PCAST, 2011; 2014; Acatech, 2013).

Given the crucial importance in the current technological scenario for firms to adopt a collaborative approach to innovation activities with other firms and institutions and for governments to define precise lines of strategies through strategic PPPs, the first empirical analysis is aimed at understanding: (i) how a specific approach to innovation and technology policy is able to stimulate the overall innovative performance and diffusion of PPPs (ii) the determinants explaining firms' propensity to be involved in PPPs. These issues will be discussed analyzing the Italian NIS, which is characterized, as will be furthered discussed in Chapter Three, by a prevalently bottom-up approach to innovation and technology policy.

Therefore, Research Question 1 (RQ1) may be formalized in the following way:

RQ1: In the context of a NIS, characterized by a specific institutional and organizational setting, what is the relationship between the approach to innovation policy, the overall innovation performance and the level of diffusion of PPPs in the system?

RQ1 may be split in two main sub-questions (RQ1a and RQ1b):

RQ 1a: In the context of a NIS, characterized by a specific institutional and organizational setting, what is the system's overall innovation and technology performance?

RQ 1b: In the context of a NIS, characterized by a specific institutional and organizational setting, what is firms' propensity to get involved in PPPs and what are the main determinants explaining this trend?

Given the substantial bottom-up/market-driven approach to innovation and technology policy of the Italian country, it may be interesting to investigate whether this approach to policy making is able or not to adequately stimulate the level of innovation and technology performance and of diffusion of collaborative innovation projects on the territory; therefore a second Research Question (RQ2) may be formulated as follows:

RQ2: Is a bottom-up approach to innovation policies sufficient to stimulate a country's overall innovative performance and level of diffusion of PPPs?

2.3.1.1. Data and Methodologies

First of all, I analyze the Italian NIS, focusing in particular on the following elements: the main features of Italy's institutional context, the approach to innovation and technology policies and the country's innovative performance in comparison to the main European industrial players. In this first step of the research, data on the institutional context and on the approach to innovation and technology are derived from some relevant and recent contributions on the topic (Virgillito and Romano, 2014; Lucchese et al., 2016), and the analysis on the innovative performance of the system is done on the basis of some relevant indicators related to the Science, Innovation and Technology performance available on the Eurostat website, the statistical office of the European Union.

Second, the analysis of the level of diffusion and the main determinants explaining firms' propensity to be involved in PPPs is done using the anonymized file of microdata stemming from the 8th wave of the Community Innovation Survey (CIS8, 2010-2012). On the basis of a literature review of the main empirical contributions on the topic (Hagedoorn et al., 2000; Belderbos et al. 2004, Veugelers and Cassiman, 2005; Fritsch and Lukas, 2001; Bayona et al. 2001, Miotti and Sachwald, 2003; Mowery et al., 1998; Caloghirou et al. 2003; Fontana et al. 2006, Lööf and Brostrom, 2008; Schartinger et al. 2002, Robin and Schubert, 2013, Schøtt and Jensen, 2016), I test the statistical significance of some main explanatory variables at industry and firm levels, through the use of a logistic model, drawing on the work of Segarra-Blasco and Arauzo-Carod (2008). Specifically, I estimate the propensity of firms to collaborate with other firms and institutions, in particular with group firms, customers and suppliers, competitors, public research centres and Universities, focusing on the cooperation with Italian and foreign Universities. In Appendix 1a, I provide a possible solution to the problem of endogeneity of some of the variables involved.

2.3.2. The case of Trento's RIS: a qualitative analysis

The analysis at national level provides some initial insights into the relationship between a prevalently bottom-up approach to innovation and technology policies, the innovative performance and the level of diffusion of PPPs in a NIS.

However, in order to understand how firms and institutions are managing the transition towards 'Industry 4.0' and how can effective innovation policies may be defined in order to facilitate this shift, the analysis of the case of the Italian country presents some limitations: first, the Italian NIS is characterized by a high heterogeneity both in terms of regional innovative performance and in terms of different approaches to innovation policies; second, the data available from the CIS 2010-2012 refer to innovation activities in very general terms and contributes weakly to the understanding of how firms and institutions are approaching the 'Industry 4.0' technological transition.

Therefore, in order to better understand the elements of an institutional and organizational framework that can positively influence the current socio-technical transition, the second step of the research is dedicated at analysing an institutional-driven RIS, which, according to the Regional Innovation Monitor Surplus, is managing successfully the technological transition (RIM, 2016): Trento.

The literature on RIS has made much progress in the understanding of innovation as a systemic process resulting from the interaction between public and private players. In recent years, scholars in Evolutionary Economic Geography have explored the nature and mechanisms of the long-term industrial change (Martin and Sunley, 2006; Boschma and Frenken, 2011), focusing on the conditions stimulating path renewal and path creation processes (Tödtling and Trippl, 2013). In the growing conviction that regions are characterized by important differences and there are no "one-size-fits all" strategies that can be universally applied (Tödtling and Trippl, 2005), the recent literature has devoted particular attention to less developed regions, classified in terms of organizational/institutional thickness/thinness stimulating particular regional development paths (Trippl et al. 2015a; Isaksen and Trippl, 2014).

Whereas the organizational dimension of RISs and the connection to regional development paths have been quite deeply explored in the literature (Trippl et al. 2015a; Isaksen and Trippl, 2014) further work is needed in order to understand how different institutions at various spatial scale can affect path development in different RIS types (Trippl et al., 2015a). Related to the institutional dimension of RISs, strategic PPPs are more and more considered important tools of innovation policy at the regional level (Kristensen and Scherrer, 2016, Wieczorek and Hekkert, 2012, OECD, 2008; OECD, 2016; Fogelberg and Thorpenberg, 2012, Smits and Kuhlman, 2004, Miozzo and Dewick, 2004). In fact, they are capable to build and strengthen interfaces between the players of the system, creating platforms for knowledge and competence exchange, increasing the entrepreneurial capacity and the overall innovative potential of a RIS (Kristensen and Scherrer, 2016; Wieczorek and Hekkert, 2012, OECD, 2008, OECD, 2016, Fogelberg and Thorpenberg, 2012, Smits and Kuhlman, 2004, Miozzo and Dewick, 2004).

The analysis of the case of Trento may be interesting for two main reasons: (1) it may contribute to the understanding of how an institutional-led RIS types, characterized by the adoption of a prevalently 'top-down' approach to innovation policy, may stimulate different path renewal and path creation processes; (2) it may contribute to the understanding of how can local PPPs positively influence the techno-economic shift at the local level, given the strict relationship between the institutional dimension of RISs and the development of strategic PPPs.

Research Question 3 (RQ3) of this second qualitative analysis may be formalized in the following way:

RQ 3: In the context of an institutional-driven RIS, what are the elements of the institutional/organizational framework which are able to positively influence local technological development, favouring the technological shift towards 'Industry 4.0'?

RQ3 may be split in two main sub-questions (RQ 3a and RQ 3b):

RQ 3a: What are the structural elements (knowledge generation and diffusion subsystem, the regional policy subsystem, the local interactions between the relevant dimensions and the socio-institutional factors) of the RIS favouring/blocking local technological development?

RQ 3b: How are the local firms and institutions approaching the shift towards 'Industry 4.0' and what is the role of strategic PPPs in favouring this shift?

Given the strong institutional character of Trento's RIS, it may be interesting to understand whether the presence of a top-down/institutional driven approach to innovation policy may be sufficient to stimulate local technological development. Therefore the Research Question 4 (RQ 4) is formulated as follows:

RQ 4: Is a top-down approach to innovation policy sufficient to trigger the cross-level synergies between the players of a RIS influencing the local technological development and thus favouring the socio-technical transition towards 'Industry 4.0'?

2.3.2.1. Data and Methodologies

For this second analysis, the methodologies adopted have been qualitative, based on the case study approach (Eisenhardt, 1989; Yin, 1994). Data are collected through both primary and secondary sources. Primary data have been gathered through 57 semi-structured interviews (30 institutional players and 27 enterprises), which have been registered, listened and fully transcribed. Specifically, they have been aimed at understanding the following elements: the measures adopted at regional level for the implementation of innovation policies supporting the digitalization of the manufacturing industry; the main PPPs and cooperation projects between public and private players on the territory aimed at accelerating the adoption of the 'Industry 4.0' KETs; the level of knowledge and adoption of the local enterprises of the 'Industry 4.0' KETs[97]. Secondary data have been gathered through previous research reports, official statistics, mass media products, government reports, web information and historical data and information.

[97] Further details concerning the questionnaire submitted to the enterprises and to the institutions are contained in Appendix 2.

3. Chapter Three: Italy's National Innovation System, Evidence from the Community Innovation Survey 2012

The present Chapter is organized as follows. The first section (3.1) contains the analysis of Italy's NIS, discussing the institutional context (3.1.1.) and the approach to innovation and technology policies (3.1.2.); moreover, it provides an analysis of Italy's innovative and technology performance with respect to some relevant indicators, in comparison to the major European countries (3.1.3.), including some important ICT indicators (3.1.3.1.). The second section (3.2) contains the results of the estimation based on the file of anonymized micro data derived from the CIS 2010-2012 for the Italian country; the first paragraph (3.2.1.) provides a systematic literature review on the main empirical contributions on PPPs; the second paragraph (3.2.2.) presents the dataset, the third paragraph (3.2.3.) the model and the explanatory variables, the fourth paragraph (3.2.4.) the descriptive statistics and the final paragraph (3.2.5.) the results of the analyses. The final section (3.3) discusses the results in light of the aforementioned research questions and concludes.

3.1. Italy's Innovation System

3.1.1. The institutional context

First of all, the Italian NIS is characterized by non-homogenous economic and social development (Virgillito and Romano, 2014). Starting from the Fifties, the Northeast regions went through the so-called 'miracle of the Third Italy', one of the most important processes of socio-economic changes with a rapid transformation of these territories in fast-growing entrepreneurial regions, thanks to the increase in R&D support by the public sector and the development of high-tech sectors, like electronics and aerospace. This process exacerbated the distance in terms of economic growth with the Southern regions, which are still characterized by a relatively weak performance in terms of some main innovation indicators in comparison to the other Italian and European regions, and a substantial lack of a systemic dimension of the innovation processes[98].

Another feature of the Italian industrial system is the prevalence of SMEs, mainly specialized in traditional sectors with low-technological intensity and organized in industrial districts which have been for a long time the object of interest of many economists[99] (Becattini, 1990; Becattini et al., 2009; Lombardi, 2003), due to the particular features of this model of local economic development. Becattini, one of main theorists of industrial district, defines the industrial district as a "socio-territorial entity which is characterized by the active presence of both a community of people and a population of firms in one naturally and historically bounded area. In the district, unlike in other environments, such as manufacturing

[98] However, in recent years some high-tech clusters have developed, particularly thanks to the financial support deriving from the European Community programs. Some examples of technological clusters in Southern regions are MEDIS, the technological district in mechatronics, the National Technological District on Energy in Apulia and the Technological District Micro and Nano Systems in Sicily.

[99] Industrial districts are for example active in different industries and in different regions: textile in Prato, Como and Carpi; footwear in Vigevano, Barletta and Casarano; furniture in Brianza and Udine; ceramic tiles in Sassuolo and Caltagirone; gold jewellery in Arezzo.

towns, community and firms tend to merge" (Becattini, 1990, p.38). Important elements of industrial districts' competitive advantage are the geographical proximity and the sharing of values and knowledge among the stakeholders of the value chain, making it possible to transmit and exchange scientific and technological knowledge between different players, reduce the uncertainty linked to the introduction of a technological innovation, integrate different competences that are outside the boundaries of the firm (Feldman, 1994). Asheim and Isaksen (2002) describe the capacity of industrial districts to achieve a long term competitive advantage due to the ability to create, combine, share knowledge flows among the clustered firms.

Many studies on industrial districts underline how the concentration of SMEs in local production systems generate, on one hand, the so-called 'collective efficiency', the competitive advantage of clustering firms, resulting from the combination of external economies and joint action, and the presence of 'systemic' entrepreneurs, playing a crucial role for the creation of new scale and scope economies (Lombardi, 2003). Lombardi (2003) defines the 'traditional' pattern of interlocking behaviours of different agents in a local production system as a cognitive architecture, which emerges 'evolutionary' as an invisible mind, in which evolutionary pressures lead new patterns of relationships and interlocking behaviours.

More recently, some contributions have underlined the importance for industrial districts, on one hand of extra-local knowledge networks, combining the 'local buzz' to 'global pipelines' (Bathelt et al., 2004) and, on the other hand, of firms' absorptive capacity, which makes it possible for district firms to translate global pipelines external knowledge into an increase of innovative performance (Boschma and Ter Wal, 2007), in order to face the global competitive pressure. In similar vein, Randelli and Lombardi (2014) analyzing the leather products cluster in Florence describe the new challenges clusters are facing in the new techno-economic landscape, highlighting the crucial role of some leading firms in acting as gatekeepers to connect local resources (and firms) to global networks.

The Italian local production systems have for a long time been mainly characterized by the prevalence of low-tech manufacturing industry, also thanks to the particular vocation of the country to high-cultural and creative activities (Lazzeretti et al., 2008). Lazzeretti (2012) highlighted the crucial role of culture and creativity for Italy's economic development, thanks to the creative capacity to stimulate economic development and to generate cross-fertilization processes (Lazzeretti et al., 2011). A recent study (Sedita et al., 2015) assessing the impact of related variety and differentiated knowledge base on the resilience of local productive systems suggested that the competitiveness of Italian firms is not centered on the most high-tech activities but in more creative fields, able to renovate more traditional manufacturing activities, such as in the case of design (Bettiol and Micelli, 2014). However, despite the prevalence of local production systems characterized by a low-tech intensity, Virgillito and Romano (2014) highlight the great expansion during the years also of high-tech activities, including for example electronics in Milan and Turin, biotech (pharmaceuticals) in Milan and Rome, industrial automation in Milan, Turin and Bologna.

A further characteristic of Italy's innovation system is represented by the lack or weak presence in most regions of "systemic interactions and knowledge flows between the relevant players (which) are simply too sparse and too weak to reveal a strong innovation system" (Virgillito and Romano, 2014, p.10). The lack of proper relations between the players of the system, together with the growing competitive pressure of the low-cost countries contributed to tighten up the consequences of the crisis, posing severe challenges to its long term survival. "The Italian context is being shaped by such crucial points as strong territorial differences in terms of both heterogeneity and historical contingency; lack of a system connecting its numerous administrative regions; highly problematic measurement issues due to persistent and significant interregional and intraregional differentiation; relatively low technological intensity of specialization patterns; and copious evidence of policy failure, particularly with respect to innovation and technology policies" (Virgillito and Romano, 2014, p. 10). The following paragraph describes more in details the approach to innovation and technology policies adopted, attempting to understand the reasons of this "copious evidence of policy failure" characterizing the Italian country.

3.1.2. The approach to innovation and technology policies

The work of Lucchese et al. (2016) offers some interesting insights on the Italian approach to innovation and technology policy and its evolution during time.

As most of the major European industrial powers, the phase of reconstruction after the Second World War has been characterized by a strong interventionism of the State, aimed at building a solid manufacturing base in strategic sectors (steel, automotive, electronics and telecommunications) and at supporting the necessary infrastructure system. In Italy, this period has been characterized by the extensive role of public owned enterprises in manufacturing, infrastructures, services and banks, which went on until the Seventies. Starting from the Eighties, some main factors began to reveal the substantial lack of dynamism of both public enterprises, affected by corruption and lack of efficiency in the use of public resources, due to the large influence of the government parties, and of private enterprises, which showed the lack of technological, production, financial, and managerial capabilities: the increasing globalization, the growing liberalization of capital movements and the strong development in Information and Communication Technologies (ICTs). As a result, starting from the Nineties, the Italian manufacturing industry and innovative capacity experienced a significant weakening.

In particular, the crisis in the industrial compartment has been due to four main reasons: the new role of intellectual property, after the World Trade Organization (WTO) TRIP agreement on Intellectual Property Right (IPR), which has made more expensive the acquisition of external knowledge for the technological imitators, like the Italian country, making it more difficult to close the technological gap with the more technological advanced countries; the frequent devaluation policies, which allowed the Italian firms to avoid more forward-looking strategies towards knowledge-intensive activities, remaining anchored to low-tech manufacturing sectors and becoming more and more exposed to the competition of the low-cost countries; the liberalization of labour markets, which made it possible for firms to get advantage of low cost labour, without engaging in investments in technological innovation, widening the competitive gap with the other

European countries; the lack of real investments in parallel to the rise of profits, stimulated also by the increase financialization of the economy, which is partially responsible for firms' short-term strategies.

In parallel, starting from the Nineties, the country experienced a consistent diminishing of the financial resources devoted to industrial policies, also influenced by the diffusion of neoliberal policies throughout the European countries; as a result, the vertical measures were abandoned, because they were considered distortive of the market efficiency and horizontal measures started to be more and more adopted, since they were considered able to support the overall competitive advantage of the economic system. As a matter of fact, the country's financial resources devoted to industrial policies more than halved between the 1992 and 2013 (Lucchese et al. 2016), with a significant reallocation in the Northern and central regions, thus exacerbating the disparities with the South.

The recent debate on the need for manufacturing-oriented industrial policies in Europe brought also the Italian country to adopt some measures aimed at supporting the innovative potential of the industrial system. Today, the main measures adopted may be divided in two main categories: government subsidies to firms[100] and interventions supporting firms' R&D activities[101]. Other technology programmes include the National Technology Clusters, a programme launched in 2012, aiming at aggregating companies, Universities, other public or private research entities in the field of innovation[102]. In 2012, the Smart Cities programme involved SMEs, large firms, Universities and public research organizations in innovative projects on social innovation for nine strategic areas, according to the Horizon 2020 Societal Grand Challenges. Finally, during the last decades, the Cassa Depositi e Prestiti (CDP) emerged as Italy's 'unofficial' public investment bank, being one of the major buyers of Italy public debt and as a private-type investment bank, involved in strategic investments, as for example the ones in wide-band telecommunication infrastructure. During the 2009-2014, private investments of the CDP increased, particularly oriented to

[100] The government subsidies include, in addition to public procurement, the following incentives: loan guarantees for SMEs, a system of loan guarantees set after the credit crunch originated by the 2008 crisis, providing support to SMEs and micro firms to fund investment through back loans; incentives for machinery investments by SMEs, consisting of soft loans supported through the Cassa Depositi and Prestiti, providing the credit for the investments with the Ministero dello Sviluppo Economico (MISE) covering the cost of interest reduction; the attraction of Foreign Direct Investments, with measures aimed at simplifying the bureaucratic procedures of foreign investors, presented in the plan "Destinazione Italia" in 2013.

[101] The interventions supporting the R&D activities include the following measures: R&D tax credits, the Patent Box, and support for start-up firms; ICTs and the Digital Agenda. R&D tax credits regard some measures introduced in 2011 for firms financing research projects in partnerships with Universities, hiring skilled workers in R&D. The patent box is a tax benefit for firms' earning deriving from patents, trademarks, licences and software; between 2015-2017 there has been an increase in the deduction from the firm's tax base: the deduction from the firm's tax base has been of the 30% of the incomes from patents, trademarks, licences and software in 2015, 50% in 2016, 50% in 2017. Although lacking for a long time in Italy, an extensive policy supporting ICTs, in 2014, MISE launched the so-called "ICT-Agenda digitale" on the KETs, supported by a "Sustainable Growth Fund". Moreover, IT vouchers for SMEs were introduced in 2014, with funding for the acquisition of IT materials; finally, the internationalization voucher for SMEs was launched by the government in 2015.

[102] There are eight main technology fields interested: fashion, pulp and paper, stone processing, boat and sea technology, furniture and furnishing, technologies for renewable energy and energy savings, life sciences, ICT technologies, nanotechnologies, sustainable city, optoelectronics and space and mechanics.

SMEs and mid-sized national champions, with an important role in private equity financing, using financing tools, including the 'Fondo Strategico Italiano', and the 'Fondo Italiano di investimento[103]'.

Also the recent national Plan for Industry 4.0, as already mentioned (X Commissione Permanente, 2016), although representing a first important attempt towards the improvement of firms' level of digitalization, it shows to be mainly anchored to an exclusive and explicit horizontal approach to policy making, based prevalently on tax credits and digital infrastructures. This aspect is in contrast to the main approaches adopted by the major industrial countries, like the U.S., Germany and UK, which, as Lombardi (2017) underlines, have implemented a mixed approach between top-down strategies and bottom-up solutions, through strategic multi-scalar PPPs. "The focus, almost exclusive, on fiscal facilities, like credit taxes and digital infrastructures, although clearly essential, runs the risk of a fragmentation of resources, in the lack of proper medium-long term orientations elaborated through public-private research partnerships, as shown by the European and American experiences" (own translation, Lombardi, 2017, p.177). Similarly, also Lucchese et al. (2016) has underlined that, despite some important recent efforts in developing an industrial policy, the measures listed show the prevalent "lack of a strategic vision, the persistence of horizontal measures, modest resources and the risk of 'falling behind' in R&D and innovation (...) " (Lucchese et al., 2016, p. 14).

In fact, these considerations are confirmed analyzing the Italian positioning in Europe in terms of some main innovative and technology performance indicators, as shown in the following paragraph.

3.1.3. The innovation performance: a comparison with some main European countries

According to the European Regional Innovation Scoreboard (2017), Italy is defined as a Moderate Innovator with its innovation performance[104] declining by the 0.2% relative to that of the European Union (EU) in 2010. Table 3 shows the summary innovation index of the Italian country, articulated in some different innovation dimensions.

The main relative strengths of the innovation system are the attractive research system, the intellectual assets and the 'innovators'. In fact, the performance related to the attractive research system increased by 21.8%, from 73.3.% to 95.1% with respect to the EU between 2010 and 2016, thanks to an increase in the international scientific co-publications (70.1%), an increase in the most cited publications (10.4%) and foreign doctorate students (21%); the index for innovators slightly decreased by the 10.8%, from 101.5% to 90.6% from 2010 to 2016, due to a strong decrease in SMEs marketing/organizational innovations (-20.9%),

[103] According to Lucchese et al. (2016), the action of the CDP lacks of a proper strategic view, partially due to its private form, which implies that its main priorities are the financial sustainability and profitability of its investments. This aspect implies that it will keep sustaining the 'healthy' companies, and will never be directed towards firms with technological potential; thus, as it is now, it is unable to support 'mission-oriented' policies for societal challenges.

[104] According to the European Regional Innovation Scoreboard (2017), innovation performance is measured using a composite indicator - the Summary Innovation Index - which summarises the innovation performance on the basis of 27 indicators. These indicators are grouped into four main types articulated in 10 innovation dimensions: framework conditions, which include human resources, attractive research systems, innovation friendly environment; investments, including finance support and firm investments; innovation activities, including innovators, linkages and intellectual assets; impacts, including employment and sales impact.

in SMEs innovating in-house (-16.3%) and a slight increase in the SMEs product/process innovations (+5.1%). Finally, the index for intellectual assets increased by the 5.6%, from 100.8% to 106.3%, due to an increase in PCT patent applications (+3.2%), in trademark applications (+20.4%), which compensate the slight decrease in design applications (-2.6%).

On the other hand, the main relative weaknesses are shown to be linked to finance and support, firm investments and linkages. The performance related to finance and support decreased of the 7.3%, from 57.4% in 2010 to 50.1% in 2016 with respect to the EU, due to a little increase in the R&D expenditure in the public sector (+5.3%), and a strong decrease in venture capital expenditures (-23.2%); firm investments slightly increased (+3.2%), due to an increase in the R&D expenditure in the business sector (7.7%) and in the enterprises providing ICT training (7.1%), compensating the decrease in non-R&D innovation expenditures (-7.5%).

Table 3: Summary of the Innovation Index of the Italian country, relative to the European Union in 2010

	Performance relative to EU in:		
	2010	**2016**	**Change 2010-2016**
SUMMARY INNOVATION INDEX	75.4	75.1	-0.2
Human resources	60.3	75.8	15.5
New doctorate graduates	107.7	102.2	-5.5
Population with tertiary education	17.8	49.3	31.6
Lifelong learning	52.6	74.7	22.1
Attractive research systems	73.3	95.1	21.8
International scientific co-publications	119.2	189.4	70.1
Most cited publications	88.8	99.3	10.4
Foreign doctorate students	34.4	55.5	21.0
Innovation-friendly environment	88.3	72.1	-16.2
Broadband penetration	55.6	55.6	0.0
Opportunity-driven entrepreneurship	111.4	83.8	-27.6
Finance and support	57.4	50.1	-7.3
R&D expenditure in the public sector	66.2	71.6	5.3
Venture capital expenditures	46.2	23.0	-23.2
Firm investments	58.7	61.9	3.2
R&D expenditure in the business sector	53.6	61.4	7.7

Non-R&D innovation expenditures	84.6	77.1	-7.5
Enterprises providing ICT training	42.9	50.0	7.1
Innovators	101.5	90.6	-10.8
SMEs product/process innovations	84.3	89.4	5.1
SMEs marketing/organizational innovations	102.3	81.4	-20.9
SMEs innovating in-house	117.6	101.3	-16.3
Linkages	48.6	44.2	-4.4
Innovative SMEs collaborating with others	48.0	55.4	7.4
Public-private co-publications	80.9	59.4	-21.5
Private co-funding of public R&D expenditure	21.3	21.9	0.6
Intellectual assets	100.8	106.3	5.6
PCT patent applications	73.2	76.4	3.2
Trademark applications	95.5	115.9	20.4
Design applications	141.9	139.4	-2.6
Employment impacts	73.6	71.4	-2.2
Employment in knowledge-intensive activities	102.6	105.1	2.6
Employment fast-growing enterprises	52.5	46.8	-5.6
Sales impacts	81.3	75.9	-5.4
Medium and high tech product exports	90.7	91.5	0.8
Knowledge-intensive services exports	68.0	66.2	-1.8
Sales of new-to-market/firm innovations	85.5	68.4	-17.1

Source: European Regional Innovation Scoreboard, 2017

This first analysis highlights the relatively good performance of the Italian country in terms of public research performance and high dynamicity of the Italian SMEs in terms of ‘innovators’, but the relatively weak propensity of firms to invest in R&D activities and to develop public-private collaborations for innovative projects. These trends are confirmed analyzing the main Science, Technology and Innovation indicators of the Italian country, in comparison to some main European countries.

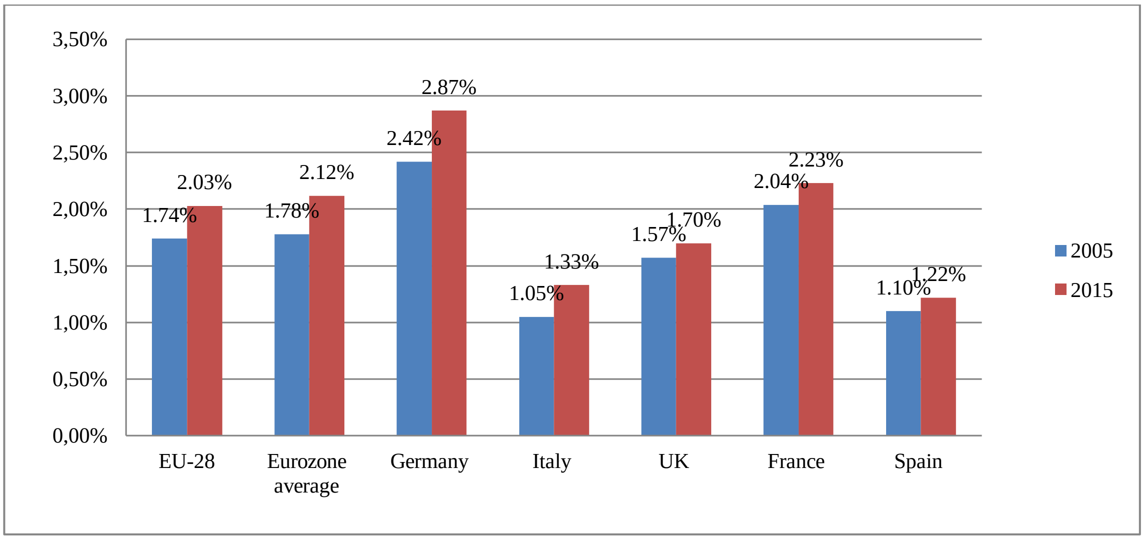
First of all, the Italian country suffers of a relatively low level of both public and private R&D investments, which are below European averages and of the main European countries taken into account in the present analysis.

Figure 5 shows data on the level of R&D intensity[105], R&D expenditure as a percentage of GDP, in five main European countries, Spain, France, United Kingdom, Italy and Germany, compared to the

[105] According to Eurostat, Research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the

Eurozone average and the average of the main 28 European countries (EU-28 averages) in 2005 and in 2015. The figure shows that the R&D intensity increased between 2005 and 2015, for each country taken into account and also at European level; in Italy, the R&D intensity shifted from 1.05% in 2005 to 1.33% in 2015, slightly above Spain with levels respectively of 1.10% and 1.22%, but below the EU-28 averages (1.74% and 2.03%) and the Euro-zone averages (1.78% and 2.12%), Germany (2.42% and 2.87%), France (2.04% and 2.23%) and the United Kingdom (1.57% and 1.70%).

Figure 5: R&D expenditure as percentage of GDP in 2005 and in 2015 in some European countries



Source: author's elaboration on Eurostat data

These trends characterize both the business and the government sectors. Table 4 shows the R&D expenditure as percentage of GDP, by sector of performance.

In the business enterprise sector, the R&D intensity increased between 2005 and 2015 both at European level and for each country taken into account; in 2015, Italy counts a total R&D expenditure of 0.74%, slightly higher than Spain (0.64%) but lower than EU-28 and Eurozone averages (1.3%), Germany (1.95%), France (1.45%) and UK (1.12%). Also in the government sector and in the higher education sector, Italy has one of the relatively lowest indicators, with substantially stable trends since 2005.

Table 4: R&D expenditure as percentage of GDP by sector of performance in some European countries

Countries/R&D indicators	R&D expenditure (total)		R&D expenditure (business enterprise)		R&D expenditure (government sector)		R&D expenditure (higher education sector)		R&D expenditure (private no-profit sector)	
	2005	2015	2005	2015	2005	2015	2005	2015	2005	2015

use of this stock of knowledge to devise new applications. R&D expenditures include all expenditures for R&D performed within the business enterprise sector (BERD) on the national territory during a given period, regardless of the source of funds. R&D expenditure in BERD are shown as a percentage of GDP (R&D intensity).

EU-28	1.74%	2.03%	1.1%	1.3%	0.24%	0.24%	0.39%	0.47%	0.02%	0.02%
Eurozone	1.78%	2.12%	1.12%	1.35%	0.26%	0.28%	0.39%	0.47%	0.02%	0.02%
Germany	2.42%	2.87%	1.68%	1.95%	0.34%	0.43%	0.38%	0.5%	.	.
Italy	1.05%	1.33%	0.53%	0.74%	0.18%	0.18%	0.32%	0.38%	0.02%	0.04%
UK	1.57%	1.70%	0.96%	1.12%	0.17%	0.12%	0.4%	0.44%	0.04%	0.03%
France	2.04%	2.23%	1.27%	1.45%	0.36%	0.29%	0.38%	0.45%	0.03%	0.03%
Spain	1.1%	1.22%	0.59%	0.64%	0.19%	0.23%	0.32%	0.34%	0	0

Source: author's elaboration on Eurostat data

Table 5 shows the levels of Gross Domestic Expenditure on R&D[106] by sources of funds, distributed between the business enterprise, the government, the high-education, no-profit sectors and abroad. Also in this case, the Italian country shows relatively low performances with respect to the other countries, with the lowest rate in 2014 in the business sector equal to 46.2%, below the Euro-area average (56.9%), EU-28 average (55.3%), Germany (65.8%), France (55.7%), the UK (48%) and slightly lower than Spain (46.4%). On the contrary, taking into account the public component of R&D expenditure, Italy has one of the relatively highest performances (40.8%), showing an imbalance with respect to the private component, according to the targets set by the Lisbon agenda.

Table 5: GDP on R&D by source of funds in 2005 and in 2014 in some European countries

Countries/GERD	**Business enterprise sector**		**Government sector**		**High-ed. sector**		**Private no-profit sector**		**Abroad**	
	2005	**2014**	**2005**	**2014**	**2005**	**2014**	**2005**	**2014**	**2005**	**2014**
EU-28	54.1%	55.3%	34.4%	32.3%	0.8%	0.8%	1.6%	1.6%	9.1%	10%
Eurozone	55.7%	56.9%	35.2%	32.9%	0.7%	0.8%	0.8%	0.9%	7%	8.5%
Germany	66.6%	65.8%	27.5%	28.8%	.	.	0.3%	0.3%	3.7%	5%

[106] According to Eurostat, this table presents the relative shares of the different sources of funds in R&D. More specifically the indicators provided are percentage of the GERD (Gross domestic expenditure on R&D) financed respectively by the industry, the government, the higher education and the private non profit sectors. The fifth source of funds shown, which also make the breakdown complete, is GERD financed from abroad. R&D is an activity where there are significant transfers of resources between units, organisations, sectors and countries. The importance of the source of funding has been recognized in one of the Barcelona targets of the Lisbon agenda where it is said that the appropriate split for R&D is 1/3 financed by public funds and 2/3 by private.

Italy	39.7%	46.2%	50.7%	40.8%	0.1%	1%	1.6%	2.6%	8%	9.3%
UK	44.1%	48%	32.7%	28.4%	1.2%	1.2%	4.7%	4.8%	19.3%	17.5%
France	50.7%	55.7%	38.6%	34.6%	1%	1%	0.9%	1%	7.5%	7.8%
Spain	48%	46.4%	41%	41.4%	4.1%	4.1%	0.9%	0.7%	5.7%	

Source: author's elaboration on Eurostat data

The analysis of some relevant indicators of the innovation performance shows that the Italian country covers the relatively lowest positions with respect to some of the main European powers (Table 6).

In 2015, Italy had a percentage of R&D personnel[107] on the active population equal to 0.9%, slightly higher than Spain (0.8%) but lower than the European averages, 1.19% for the EU-28, and 1.26% for the Eurozone, United Kingdom (1.31%) and Germany (1.49%).

Data on the share of governmental expenditure in R&D activities[108] reveals that there has been a decrease of this rate between 2005 and 2015 for each country and at European level, except for Germany, which increased the share of governmental expenditure from 1.6% to 2%. Italy covers the last position with a level of 1.01% in 2015 following Germany (2%), the Euro area and Euro-28 averages with, respectively, values of 1.42% and 1.38%, Spain (1.29%), UK (1.26%) and France (1.14%). In the industry sector, Italy positions itself in the relatively lowest level of turnover from innovation[109] in 2012 (11.9%) following the UK (32.5%), Germany (19%), Spain (17.8%), and France (17.5%). In the service sector instead, Spain covers the first position with a level of (11.3%), followed by France (10.7%), UK (9.9%), Italy (9.8%) and Germany (6.5%). For each country taken into account and at European level, the value of the high-tech exports[110] increased between 2007 and 2015. France covers the first position with a value of high-tech exports in 2007 and 2015 of, respectively, 16.7% and 21.6% higher than the EU-28 averages of 16.1% and 17%; UK with levels around 16.8%, Germany with levels of respectively 13% and 14.8%, Italy, 6% and 6.9% and Spain, 4.2% and 5.4%.

[107] According to the Eurostat definition, R&D personnel include all persons employed directly on R&D, plus persons supplying direct services to R&D, such as managers, administrative staff and office staff. The measure shown in this table is the total R&D personnel in full time equivalents as a percentage of the economic active population.

[108] Data on the Government Budget Appropriations or Outlays on Research and Development (GBAORD) refer to budget provisions, not to actual expenditure, i.e. GBAORD measures government support for R&D using data collected from budgets. The GBAORD indicator should be seen as a complement to indicators based on surveys of R&D performers, which are considered to be a more accurate but less timely way of measuring R&D activities. In this table, total GBAORD is expressed as a percentage of total general government expenditure.

[109] Turnover from innovation in the industrial and service sectors are defined as the ratio from products new to the enterprise and new to the market as a % of the total turnover. An innovation is a new or significantly improved product, good or service introduced to the market or the introduction with an enterprise of a new or significantly improved process. It is based on the CIS and covers at least all enterprises with 10 or more employees.

[110] Data on high-tech exports show the share of exports of all high technology products in total exports. They are defined according to SITC Rev.4 as the sum of the following products: Aerospace, Computers-office machines, Electronics-telecommunications, Pharmacy, Scientific instruments, Electrical machinery, Chemistry, Non-electrical machinery, Armament. The total exports for the EU do not include the intra-EU trade

Data on venture capital[111] as a percentage of GDP in 2015 show that the share of venture capital investment on GDP decreased from 2007 to 2015 for each country taken into account and the countries with the relatively weakest performances in 2015 are Italy (0.002%), followed by Spain (0.01%), Germany (0.025%), UK (0.032%) and France (0.034%).

Data on patent applications to the European patent office[112] (EPO) per million of inhabitants in 2003 and in 2014 reveal a relatively low propensity to patent of the Italian industry with one of relatively lowest levels of patent applications per million of inhabitants in 2014, equal to 69.6, higher than Spain (32.5), far lower than Germany (256.9), France (138.7), the EU-28 average (111.9), the Eurozone average (135.2) and the UK (83.5). Limiting the statistics to the high-tech patent applications[113], the same trend is confirmed, with Italy with the relatively lowest level of applications in 2013 (5.04), following Spain (7.4), the UK and the European average, around 15.7, the Euro area average (18.1), France (25.9) and Germany (27.6).

Table 6: Innovation indicators for some European countries in several years

Countries/innovation indicators	R&D personnel		Government budget on R&D		Turnover from innovation (industry)		Turnover from innovation (services)		High Tech exports		Venture Capital investments		Patent applications to the EPO		High-Tech patent applications to the EPO	
	2005	2015	2005	2015	2004	2012	2004	2012	2007	2015	2007	2015	2003	2014	2002	2013
EU-28	0.96%	1.19%	1.5%	1.38%		16.9%	8.7%		16.1%	17.0%	.	.	107.9	111.9	23.8	15.7
Eurozone average	1.02%	1.26%	1.53%	1.42%	.	.	.	.	.	.	.	.	134.9	135.2	28.7	18.1
Germany	1.17%	1.49%	1.62%	2%	23.3%	19%	11.8%	6.5%	13%	14.8%	0.034%	0.025%	269.1	256.9	49.0	27.6
Italy	0.73%	0.99%	1.36%	1.01%	11.5%	11.9%	12.6%	9.8%	6%	6.9%	0.002%	0.002%	76.9	69.6	9.1	5.04
UK	1.09%	1.31%	1.51%	1.26%	16.7%	32.5%	12.8%	9.9%	16.8%	16.7%	0.076%	0.032%	95.3	83.5	27.1	15.7
France	1.27%	.	1.78%	1.14%	16.4%	17.5%	7.5%	10.7%	16.7%	21.6%	0.035%	0.034%	128.6	138.7	30.8	25.9
Spain	0.83%	0.88%	1.39%	1.29%	15.4%	17.8%	12.4%	11.3%	4.2%	5.4%	0.034%	0.010%	23.02	32.5	3.5	7.4

Source: author's elaboration on Eurostat data

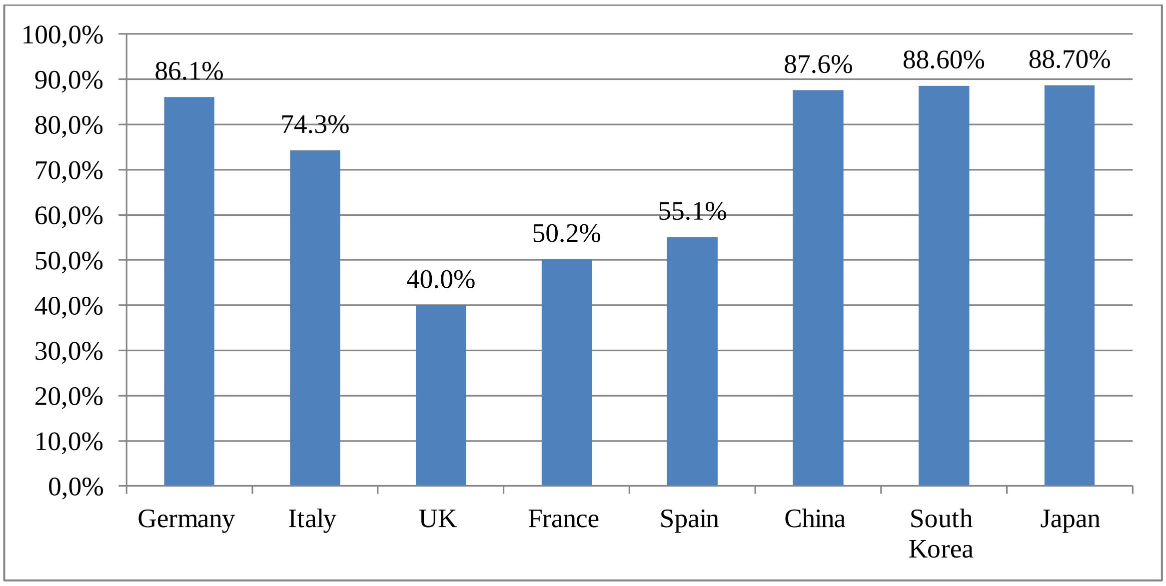
[111] The data shows the total venture capital expressed as a percentage of GDP (Gross domestic product at market prices). Venture capital investment (VCI) is a subset of a private equity raised for investment in companies not quoted on stock market and developing new products and technologies. It is used to fund an early-stage (seed and start-up) or expansion of venture (later stage venture).

[112] The total European patent applications refer to the requests for protection of an invention directed either directly to the European Patent Office (EPO) or filed under the Patent Cooperation Treaty and designating the EPO (Euro-PCT), regardless of whether they are granted or not. The data shows the total number of applications per country. If one application has more than one inventor, the application is divided equally among all of them and subsequently among their countries of residence, thus avoiding double counting.

[113] The data refers to the ratio of patent applications made directly to the European Patent Office (EPO) or via the Patent Cooperation Treaty and designating the EPO (Euro-PCT), in the field of high-technology patents per million inhabitants of a country. The definition of high-technology patents uses specific subclasses of the International Patent Classification (IPC) as defined in the trilateral statistical report of the EPO, JPO and USPTO.

Despite the relatively weak performance of these indexes, the Italian country confirms its strong manufacturing industry, presenting one of the relatively highest percentages of R&D expenditure in the manufacturing industry in 2013 (Figure 6) on the total R&D expenditure, reaching the 74.3% following Germany (86.1%), China (87.6%), South Korea (88.6%) and Japan (88.7%), but above UK (40%), France (50.2%), Spain (55.1%)

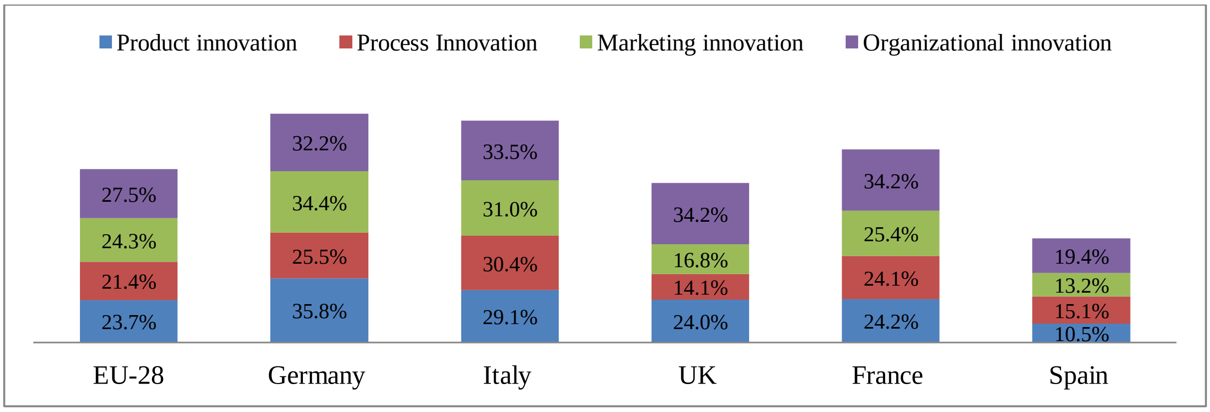
Figure 6: R&D expenditure in the manufacturing sector in 2013 in some European and extra-European countries



Source: COTEC (2016) elaboration on Eurostat data

Moreover, data on the innovative firms in the main European countries, by type of innovation introduced in 2012, according to the CIS 2012 survey (Figure 7) show a relatively high dynamicity of the Italian companies in terms of product, process, marketing and organizational innovations, as highlighted in the European Regional Innovation Scoreboard (2017). The country emerges as one of the countries with the relatively highest percentages of firms introducing product and process innovations (respectively 29.1% and 30.4%), above the European average and in line with Germany.

Figure 7: Innovative firms by type of innovation in some European countries in 2012



Source: author's elaboration on Eurostat data

This is confirmed by data on employment in high and medium-high tech manufacturing sector (Table 7) showing that, while having the relatively lowest percentage of human resources in science and technology[114] in 2016 (35.7%), Italy has one of the relatively highest levels of employment in high and medium-high tech manufacturing sector (6.1%), following Germany (9.8%), in line with the European averages and higher than France (4.4%), Spain (3.9%) and the UK (3.7%). On the contrary, the values of the employment in the Knowledge Innovation Services (KIS) sector reveal that UK is at the first position with a value of 49% in 2016, followed by France (46%), Germany (40.5%), the European averages around 40%, Spain (35.9%) and Italy (34.6%).

Table 7: Human resources in science and technology and employment in high and medium-high tech sectors and KIS in some main European countries[115]

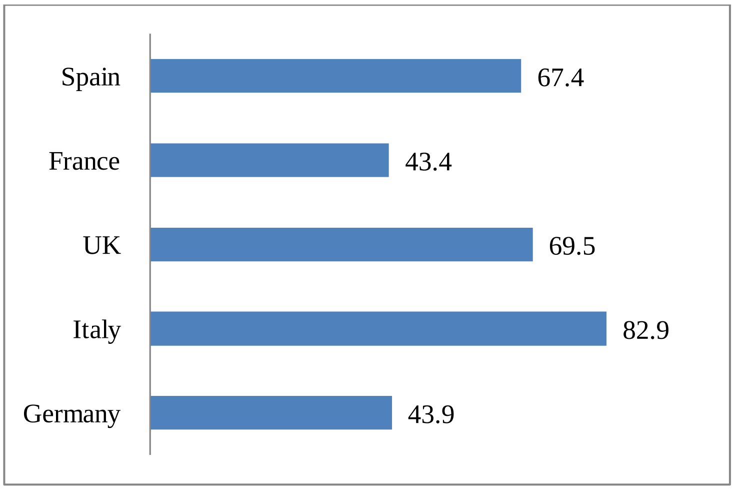
Countries/Employment indicators	**Human resources in Science and Technology**		**Employment in high and medium high-tech manufacturing**		**Employment in KIS**	
	2005	**2016**	**2008**	**2016**	**2008**	**2016**
EU-28	37.8%	46.0%	5.9%	5.8%	37.0%	40.0%
Eurozone average	39.0%	45.6%	6.2%	6.1%	37.3%	40.1%
Germany	43.0%	48.4%	9.9%	9.8%	38.7%	40.5%
Italy	32.8%	35.7%	6.0%	6.1%	33.6%	34.6%
UK	41.3%	56.9%	4.7%	3.7%	46.2%	49.0%
France	40.2%	50.5%	5.4%	4.4%	43.0%	46.0%
Spain	38.9%	43.4%	4.0%	3.9%	30.9%	35.9%

Source: author’s elaboration on Eurostat data

Together with a large manufacturing industry, Italy is also characterized by a relatively high quality level of its public research system; the country covers the first position with a number of scientific publications each 100 researchers in 2013 equal to 82.9 (Figure 8); moreover it is included in the top ten countries in terms of scientific publications (Table 8).

[114] The indicator of the human resources in science and technology (HRST) measures the share of the active population in the age group 25-64 which successfully completed an education at the third level or being employed in science and technology, as a percentage of total active population.
[115] The data shows the employment in high- and medium-high technology manufacturing sectors (code C_HTC_MH) and in knowledge-intensive service sectors (code KIS) as a share of total employment. The definition of high- and medium-high technology manufacturing sectors and of knowledge-intensive services is based on a selection of relevant items of NACE Rev. 2 on 2-digit level and is oriented on the ratio of highly qualified working in these areas.

Figure 8: Scientific publications each 100 researchers



Source: COTEC (2016) elaboration on Eurostat data

Table 8: Top ten countries in terms of scientific publications

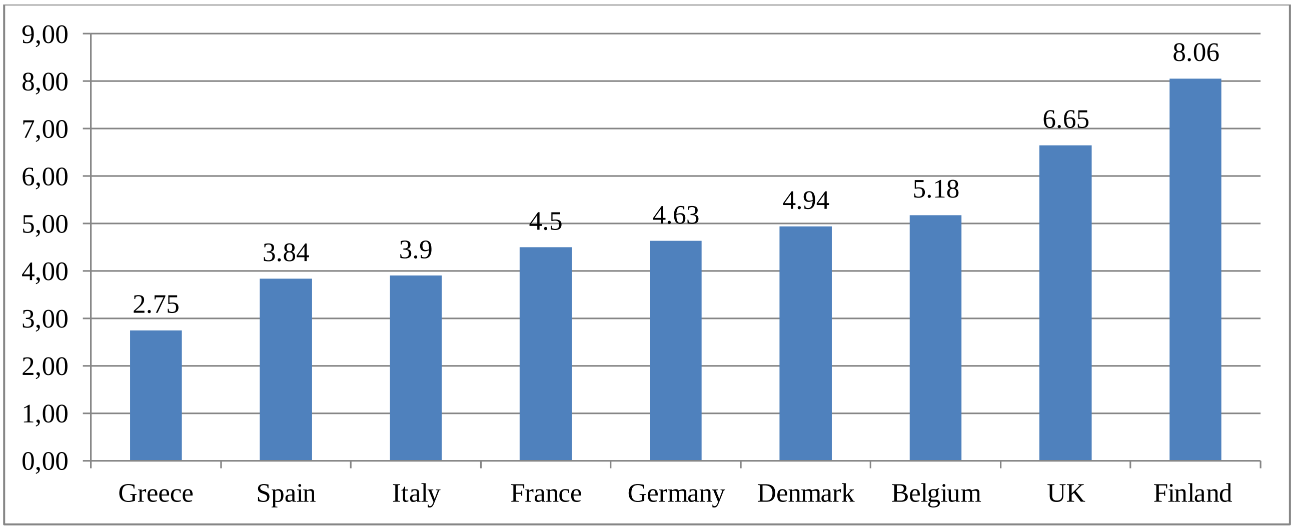
SCImago (1996-2010)				
Countries	**Documents**	**Citations**	**Cite per document**	**H index**
U.S.	23.8%	34.5%	20.2%	1229
China	8.3%	2.5%	5.7%	316
UK	6.8%	8.4%	17.4%	750
Japan	6.5%	5.6%	11.7%	568
Germany	6.2%	7.0%	15.8%	657
France	4.6%	4.9%	15.1%	604
Canada	3.5%	4.2%	17.6%	580
Italy	3.4%	3.4%	14.5%	515
Spain	2.6%	2.3%	13.1%	412
India	2.4%	1.1%	7.3%	256

Source: Banca d'Italia (2014)

3.1.3.1. The ICT sector

The analysis of the ICT sector reveals a relatively weak performance of the Italian country, with respect to some main European countries (Figure 9). Taking into account the share of the ICT in GDP in 2014, the country has one of the relatively lowest performances (3.9%), following France (4.5%), Germany (4.63%), Denmark (4.94%), Belgium (5.18%), UK (6.65%) and Finland (8.06%) and followed only by Greece (2.75%) and Spain (3.84%).

Figure 9: Share of the ICT sector in GDP[116] in 2014



Source: author's elaboration from Eurostat data

Table 9 shows data on the ICT usage in the Italian enterprises (with more than 10 employees), taking into account a number of relevant technologies related to the 'Industry 4.0' paradigm: Enterprise Resource Planning (ERP) software, Customer Relationship Management (CRM) software, Supply Chain Management (SCM) software, Cloud Computing Services, Big Data Analytics and the adoption of security policies.

As can be seen, the Italian country shows relatively good performances in relation to the adoption of ERP software, or software package to share information between different functional areas, confirming the vocation of the country towards manufacturing activities, which are adapting to more efficient and flexible processes. The Italian trend is close to the European average and to Germany, but is still worst than Belgium, Denmark, the Netherlands and Finland. The same can be said for the rate of enterprises having adopted Cloud Computing Services, close to the European Union and to Germany, but lower than the Northern European countries.

A relatively worst trend characterizes the Italian firms having adopted software, like CRM, used to analyse information about clients for marketing purposes: this percentage is lower than the European

[116] Since 2008, the ICT sector is based on NACE Rev. 2 classification as follows: ICT Total (261 + 262 + 263 + 264 + 268 + 951 + 465 + 582 + 61 + 62 + 631) ICT Manufacturing (261 + 262 + 263 + 264 + 268) ICT Services (951 + 465 + 582 + 61 + 62 + 631). The share of the ICT sector in GDP is measured using the value added (VA) concept = VA at factor cost of ICT sector / VA at factor costs of all NACE sectors x 100.

average, Germany, and most of the European countries taken into account. These results are in line with the analysis of Schivardi (2016) who has analyzed the level of adoption of some key ICT comparing the Italian and the German countries. He notices that, whereas the rate of adoption of the technologies aimed at making the production processes more efficient, like ERP software, is comparable to the German firms, size being equal, the rate of adoption of the technologies linked to improving the marketing processes, like CRM, is significantly lower with respect to the German companies, also taking into account the size variations; he suggests that a possible reason for this result may be the fact that the comparative advantage of the Italian firms is more linked to the 'production' side rather than to the 'consumer' side.

Concerning the adoption of SCM software integrating the customers/suppliers network, the Italian country shows a relatively low performance in 2014 (5%) with respect to both the European average and the main countries taken into account; this may be due, like Schivardi (2016) suggests, to the highly fragmented supply chain network, due to the prevalence of micro and SMEs in the Italian industrial system.

However, the consistent increase in the rate of adoption of SCM in 2017, shifting to the 30% of the firms, may be due to the positive effects of the 'Industry 4.0' plan, implemented in Italy at the end of 2016, which may have induced many firms to get advantge of the incentives for the investments in the 'Industry 4.0' KETs, including the adoption of SCM software. A relatively good performance is in the adoption of software for Big Data analytics, in line with the European averages and with Germany, but still lower than the Northern European countries; the particularly high rate of firms having adopted ICT security policies is possibly due to the relatively high rate of enterprises having experienced related security incidents that resulted in the unavailability of ICT services, as can be seen in the table here below.

Table 9: ICT usage in the enterprises (percentages of enterprises[117])

Countries	ERP[118]		CRM[119]		Integration with customers/suppliers, Supply Chain Management[120] (SCM)		Cloud Computing Services[121]		Big data[122]	ICT security policy[123]	ICT related security incidents
	2014	2017	2014	2017	2014/2015	2016/2017	2014	2016/2017	2016	2015	2010
EU (28 countries)	31	34	20	21	11	18	19	21	10	32	12
Germany	35	38	24	26	12	17	11	16	6	29	7
Greece	37	37	13	15	4	6	8	11	11	23	23
Spain	36	46	27	28	10	32	14	24	8	35	19
France	35	38	15	18	15	15	12	17	11	27	6

117 These data take into account all enterprises with 10 or more employees, in all sectors expect the financial one.

118 These data refer to the percentage of enterprises having adopted software packages to share information between different functional areas.

119 These data refer to the percentage of enterprises having adopted software packages to analyse information about clients for marketing purposes.

120 These data refer to the percentage of enterprises sharing information electronically on the Supply Chain Management under the following aspects: exchanging all types of information with suppliers and/or customers in order to coordinate the availability and delivery of products or services to the final consumer; including information on demand forecasts, inventories, production, distribution or product development; via computer networks, not only the internet but also other connections between computers of different enterprises; excluding normal e-mail messages manually written.

121 These data refer to the percentage of enterprises having bought Cloud Computing Services used over the Internet.

122 These data refer to the percentage of enterprises analyzing Big Data from any data source.

123 These data refer to the percentage of enterprises having a formally defined ICT security policy.

Italy	36	37	18	18	5	30	40	22	9	43	16
United Kingdom	12	19	17	21	11	5	24	35	15	35	4
Belgium	47	54	22	27	11	16	21	40	17	32	12
Denmark	42	40	24	23	59	64	38	51	12	38	12
Netherlands	40	48	27	28	11	19	28	35	19	29	19
Finland	39	39	30	23		72	51	66	15	37	26

Source: author's elaboration on Eurostat data

The data showing a significant gap of the Italian country with respect to the other countries concern in particular the rate of enterprises having developed ICT training courses and employing ICT specialists. Table 10 here below shows that the Italian firms have the relatively worst performance related to these indicators, with 2.6% in the former case and the 13% in the latter case, significantly lower than the European averages and all the countries taken into account in the analysis, except from Greece.

Table 10: Percentages of firms employing ICT specialists and developing training courses for upgrading ICT skills

	Training to develop/upgrade ICT skills of their personnel[124]	Employed ICT specialists in employment[125]
	2017	**2016**
EU (28 countries)	21	3.7
Germany	28	3.7
Greece	12	1.4
Spain	23	3
France	19	3.8
Italy	13	2.6
United Kingdom	26	5.1
Belgium	35	4.2
Denmark	27	4.2
Netherlands	24	5
Finland	38	6.6

Source: author's elaboration

Despite some recent improvements in the Italian firms' level of digitalization, also due to the recent implementation of the 'Industry 4.0' plan, a substantial delay of the Italian country with respect to the other countries emerges; the works of Rossi (2003) and of Giunta and Rossi (2017) suggest some important reasons for this lag, partially linked to the structural features of the Italian industrial system, described in paragraph (3.1.1.).

One of the main reasons concerns the size of the Italian companies, which are prevalently micro, small and medium: the highly fragmented industry makes it difficult for the Italian companies to fully exploit the potential of the ICT; moreover these firms, often concentrated in industrial districts, are characterized by more informal ways of communications, thus explaining part of this delay. In addition, the Italian industry is based on the prevalence of low-tech and creative sectors, which make the Italian companies less suitable to

[124] These data refer to the percentage of enterprises having developed ICT training courses to upgrade the ICT skills of their personnel.
[125] These data refer to the percentage of ICT specialists in total employment.

get advantage of these technologies: this trend is worsened by the relatively low presence of companies 'producing' ICT, which implies a low level of interaction with the potential buyers of these technologies, to the detriment of the overall system's efficiency. Moreover, if a company is both 'small' and 'traditional' this negative effect exacerbates. Also the management capacities of the Italian companies, often based on a family-owned resistant to change approach, are one of the main reasons explaining this resistance. In fact, as Giunta and Rossi (2017) underline, there is a "strict relationship between the adoption of the ICT and the organizational changes. The organizational processes are necessary because the new technologies imply changes in the mode and speed of communication, being the condition through which companies may fully realize the increase in productivity these technologies enable" (own translation, Giunta and Rossi, 2017, p. 114). Other reasons for the Italian overall relatively weak performances in this sector are the large distance in performances between the Northern and the Southern regions and the approach of the educational system, which is still highly related to a more humanistic and less scientific approach, which makes it more difficult to motivate the new generations in specializing in high-tech activities (Rossi, 2003).

In order to better understand the features of the Italian innovative firms and the main determinants explaining Italian firms' propensity to get involved in formal collaborative R&D agreements, the following section analyzes the features of the Italian innovative companies and provides an econometric estimation aimed at understanding the reasons which bring firms to get involved in formal PPPs, specifically, formal R&D agreements with public-private players. After reviewing the main empirical contributions on the topic, I present and discuss the results of the econometric estimation.

3.2. Evidence from the Community Innovation Survey 2010-2012

3.2.1. Literature review on the empirical studies on PPPs

Theoretical approaches to PPPs

In the last two decades, there has been a proliferation of studies trying to understand the determinants of firms' propensity to cooperate for innovation activities with external partners.

Hagedoorn et al. (2000) provide a literature review of the main theoretical rationales explaining the reasons leading to the development of a research partnership. According to the authors, PPPs refer to "cooperative arrangements engaging companies, Universities, and government agencies and laboratories in various combinations to pool resources in pursuit of a shared R&D objective[126]" (p. 568). The authors describe three main theoretical rationales explaining the incentives and the expected results deriving from research partnerships: the transaction cost theory, the strategic management theory and the industrial organization theory. Table 11 summarizes the main points of these theories.

[126] Research partnerships are divided in formal partnerships, which include research corporations that are equity based, and research joint ventures, and informal partnerships, based on undefined arrangements.

According to the transaction cost theory (Williamson, 1975), research partnerships are justified as a hybrid form of organization between the market and the hierarchy, able to minimize the cost of transactions involving intangible assets, like technical knowledge, circumvent incomplete contracts, avoid opportunistic market behaviours and high costs of internalizing the research activity. The strategic management literature articulates in five main approaches: the competitive force approach, partly deriving from the traditional structure-conduct-performance paradigm of the industrial organization theory (Porter, 1986), which considers collaboration as a means of shaping competition by improving firms' comparative competitive position; the strategic networks approach (Miles and Snow, 1984) which focuses on the importance of networks as a means to exploit the different competencies of a group of firms within a quasi-organizational framework; the resource-based view of the firm (Penrose, 1959) for which the access to external complementary resources is necessary in order to enhance and fully exploit the existing resources, which are valuable, rare and not easily replicable (Teece, 1986); the dynamic capabilities (Teece et al., 1997), the ability to integrate, build and reconfigure internal and external competencies to address rapidly changing environments, which may be facilitated by cooperation with external partners; the strategic options to new technologies, which is an extension of the dynamic capabilities approach, for which research partnerships are considered as a way to optimize the firm's strategic options, supporting it to respond to new opportunities in the presence of high market and technological uncertainty.

Finally, the industrial organization approach explains the need for research partnerships on the basis of the market failure approach: the 'public' nature of knowledge and the difficulties in appropriating the returns from the knowledge activity are insufficient incentives to invest in it. The industrial organization approach brought to the development of game theoretic models, explaining, on one hand, the under-investment and duplication of non-cooperative R&D, the non-tournament models, on the other hand the over-investment in R&D, the tournament models. According to the industrial organization theory, research partnerships make it possible to share R&D costs, pool risks, realize economies of scale and scope and increase market power.

Table 11: Theoretical explanations of research partnerships

Question	Transaction cost	Strategic Management	Industrial Organization
Incentives to form a research partnership	Minimize cost of transactions involving intangible assets (technical knowledge)	Share R&D costs	Share R&D costs
	Circumvent incomplete contracts	Pool risks	Pool risks
	Avoid opportunistic market behaviour	Economies of scale and scope	Economies of scale and scope
	Avoid high costs of internalizing the activity	Co-opt competition	Co-opt competition
		Improve competitive	Accelerate return on

		position	investments
		Coordinate value chain with coalition partners	Access complementary resources
		Increase efficiency, synergy, power through network	Decelerate rate of innovation
		Access complementary resources to exploit own resources	Increase market power
		Use collaboration as learning vehicle to accumulate and deploy new skills and capabilities	
		Learn from partners; transfer technology	
		Create new investment options	
Expected results of research partnerships Partners	Successfully meet incentives	Successfully meet incentives	Successfully meet incentives
		Interdependency	Interdependency
			Increase R&D efficiency
			Increase flow of information
Industry, society	Better resource allocation	Industry competitiveness	Increase overall R&D expenditures when spillovers are high
			Increase Social welfare
			Subsidize on certain occasions

Source: Hagedoorn et al. (2000)

Determinants of firms' propensity to collaborate with external partners, specifically with Universities

Starting from 2000, a high number of contributions sought to test empirically these theories, highlighting different aspects influencing firms' propensity to collaborate with external partners for innovation. Table 12 synthesizes some of the most relevant empirical works on the topic and lists some of the main determinants identified.

First of all, many contributions focus on the relevance of industry and firm level characteristics as important factors explaining firm’s propensity to collaborate, drawing mainly on the strategic management and on the industrial organization theories.

Industry-level features together with the level of technological complexity have been identified as relevant explanatory variables for R&D cooperative activities; drawing on Caloghirou et al. (2003), De Faria et al. (2010) describe the growing importance over the years of being part of high-technological sectors for cooperation partnerships; during most of the 1970s, before the diffusion of biotechnology and advanced materials research, high-technology sectors were responsible for 40% of the innovation cooperation partnerships, shifting to 60% during the late 1970s and early 1980s and to the 80% of recent times. De Faria et al. (2010) provide evidence that firms from high-technological industries place greater value on cooperation partners in the innovation process. Bayona et al. (2001) suggest that belonging to a high technological intensity sector increases the probability of establishing cooperative relationships and similarly Miotti and Sachwald (2003) underline that firms in more technology-intensive sectors have a greater propensity to establish cooperative R&D and innovation agreements; Dachs et al. (2008) suggest that the collaborative behaviour is more likely in high technology industries, due to the higher degree of complexity as well as to their speedier processes of knowledge generation and use. The growing technological complexity, along with the increasing speed and market globalization are the underlying reasons for the growing level of these relationships (Tether, 2002; Dachs et al. 2008). Segarra-Blasco and Arauzo-Carod (2008) found that firms in the service industry with a high technological level are more likely to be involved in formal cooperative agreements with other firms from the same group, with customers and suppliers, and with competitors, Universities and public centres, while firms in the manufacturing industry with a high technological level tend to cooperate more with competitors, Universities and public research centres.

Veugelers and Cassiman (2005) show that firms in the chemical and pharmaceutical industry are more likely to engage in industry-science links; Miozzo and Dewek (2004) analyze whether inter-organizational cooperation enhances or not firm performance in the construction industry, providing evidence of positive effects from the collaboration with Universities. Lööf and Brostrom (2008) find a positive influence of University collaboration on the innovative activity of manufacturing firms, while the association between University collaboration and service firm’s innovation output is shown to be insignificant. In contrast, Schartinger et al. (2002) suggest that knowledge interaction between industry and University is characterized by a complex pattern, based on some main elements: first, the interactions are not limited to few industries and science fields, but involve a large number of scientific disciplines, and almost all sectors of economic activities exchange knowledge in the course of industrial innovation; moreover, some traditional manufacturing and service sectors and some basic research oriented science fields are significantly involved in innovation-related knowledge interaction with Universities and industry.

Concerning firms' specific features, the first important factor to mention is the size of the firm involved.

Belderbos et al. (2004), drawing on the industrial organization theory, highlight that larger firms have a higher propensity to engage in any kind of R&D cooperation; Veugelers and Cassiman (2005) and Lòpez (2008), referring to the industrial organization and strategic management theories find that firm size is a significant and positive determinant of R&D cooperation; moreover, Fritsch and Lukas (2001) provide evidence that firms that are engaged in R&D cooperation tend to be relatively large with a comparatively high share of R&D employees and similarly Negassi (2004) shows that R&D cooperation increases with size; Miotti and Sachwald (2003) include size as a relevant explanatory variable for firms' tendency to cooperate and Bayona et al. (2001) find out that large sized firms resort more to cooperation. Also Segarra-Blasco and Arauzo-Carod (2008) provide evidence of the importance of size on firm's propensity to cooperate. Concerning the cooperative agreements with Universities, Fontana et al. (2006), drawing on the strategic management approach, highlight that the propensity to forge an R&D agreement with an academic partner depends on the absolute size of the industrial partner; similarly, also Lööf and Brostrom (2008) strongly suggest that University collaboration has a positive influence on the innovative activity of large firms.

A wide range of studies in the strategic management literature highlights the importance of firms' absorptive capacity in influencing their propensity to cooperate (Abramovsky et al., 2005; Cassiman and Veugelers, 2002; Bayona et al. 2001; Miotti and Sachwald, 2003; Fontana et al., 2006; De Faria et al., 2010; Dachs et al., 2008; Becker and Dietz, 2004, Mowery et al., 1998; Segarra-Blasco and Arauzo-Carod, 2008).

First of all, Mowery et al. (1998) highlight that one of the crucial motivations for the creation of alliances is the will of partners to acquire capabilities from an external source. According to Abramovsky et al. (2005), firm's absorptive capacity, the capability to take advantage of knowledge generated elsewhere, impacts positively on the probability of being a successful innovator and is positively related to the propensity of collaborating with other firms and institutions; Cassiman and Veugelers (2002) show that firms which consider incoming spillovers as the most important inputs to the innovation process and that are more effective in appropriating the results from the innovation processes, are more likely to cooperate in R&D activities; Bayona et al. (2001) highlight that in order to undertake cooperative R&D, certain internal capacities in this area are necessary, validating the absorptive capacity approach.

Similarly, Miotti and Sachwald (2003) provide evidence that firms engage in R&D cooperation in order to complement their internal resources and that firms' characteristics are more important than public incentives aiming at promoting specific patters of cooperation. Dachs et al. (2008) underline that the higher is the management of appropriability the higher is the probability to collaborate with external players for innovation activities. Fritsch and Lukas (2001) identify some main firm-specific characteristics, which are common to most of the firms engaged in R&D: they tend to have a comparatively high share of R&D employees, to spend resources for monitoring external developments relevant to their innovation activities and are characterized by a relatively high aspiration level of their product innovation activities. According to

Becker and Dietz (2004) R&D cooperation is aimed at complementing internal resources for innovation, validating the absorptive capacity theory. In this respect, Negassi (2004) assert that R&D cooperation increases with R&D intensity. More recently, De Faria et al. (2010) showed that firms with higher levels of absorptive capacity and of innovation investment, giving importance to incoming spillovers management, place greater value on cooperation partners in the innovation process. According to these authors, also the employees' education level, export share and appropriability have a significant impact on the probability of cooperation.

As for the cooperative agreements with Universities and research centres, Fontana et al. (2006) highlight that firms' openness to the external environment, measured by their willingness to search, screen and signal, significantly affects the development of R&D projects with Public Research Organizations (PRO). Similarly, Monjon and Walbroeck (2003) assess the importance of information flows from Universities to innovative firms, trying to determine the relative contribution of formal and informal collaboration in this process; they find that highly innovative firms derive most benefits from collaborative research with foreign Universities; they are often at the frontier of the academic knowledge in their industry and find new forms of knowledge through the cooperation with foreign Universities. Also in Segarra-Blasco and Arauzo-Carod (2008), firms' innovativeness, proxied by performing both process and product innovations is found to be a significant variable affecting firm's propensity to cooperate with Universities.

Some studies tried to find a correlation between the collaboration with Universities or with the public actor in general and the type of innovation realized, product or process innovation, radical or incremental. For example, Belderbos et al. (2006) find that the nature of cooperation partners influences the innovation success: while competitor and supplier cooperation are related to incremental innovations, customers and public sector institutions are crucial sources of knowledge for firms pursuing radical innovations. On the other side, Freel and Harrison (2006) find that, while cooperation with customers and the public sector have a positive influence on product innovation success, cooperation with suppliers and Universities impacts positively on process innovation. Differently, Robin and Shubert (2013) evaluated the impact of cooperation with public research on firms' product and process innovations finding that the cooperation with public research increases product innovation, but has no effect on process innovation, which depends more on firms' openness. Many studies underline the role of dyadic factors (Gussoni, 2009) like technological overlap to explain how partner selection occur; Mowery et al. (1998) provide evidence that partner selection can be predicted by measures of technological overlap; later on, Sampson (2007) shows that alliances contribute more to firm innovative performance when technological diversity is moderate, that is, neither when it is too high, otherwise they would have difficulty in learning from their partners, or too low, otherwise they would have nothing to learn from each other.

As underlined in Gussoni (2009), other firm characteristics which are relevant in the decision to cooperate or not are represented by the role of Foreign Multinational Companies (FMC), costs and risk.

Concerning the role of FMC, Tether (2002) finds out that for a given size, firms belonging to a wider company group are more likely to engage in innovation than independent firms, and those companies which are part of the foreign owned groups were the most likely to engage in innovation; similarly, Belderbos et al.

(2004) show that cooperating firms tend to be often part of a foreign group. Concerning the importance of costs and risk, Cassiman and Veugelers (2002) observe that high costs and low risks are relevant for cooperation with research institutes, while Belderbos et al. (2004) find out that risk sharing and access to complimentary knowledge faced with internal resource constraints appear important motivations for firms to seek R&D partners. Finally Miotti and Sachwald (2003) consider high cost and high risk as the main determinants of R&D cooperation. According to Veugelers and Cassiman (2005), cooperative agreements are typically developed to share costs. Similarly, Lòpez (2008) identifies in cost risk sharing the most important determinant for R&D cooperation, suggesting the importance of the lack of external private finance and the lack of venture capital investment for innovative activity. Also Segarra-Blasco and Arauzo-Carod (2008) find that firms belonging to a group tend to establish R&D cooperation agreements with other partners.

Among the main regional/national country factors, local, regional, national and European policy tools are generally considered important drivers for R&D cooperative agreements; Veugelers and Cassiman (2005) considers public funding to have an indirect influence on the propensity to cooperate in R&D; Miotti and Sachwald (2003) provide evidence of a positive impact of public funding on the propensity of firms to cooperate for innovation activities, in particular with the public actor. On the contrary, Belderbos et al. (2004) did not find a statistically significant result concerning the impact of public funds on firms' probability to be involved in R&D cooperation. Similarly, Evangelista (2007) did not find any significant additional effect of the reception of public financial support on the increase in turnover derived by innovations, neither on the propensity to interact and cooperate with external partners. Public funding programs affect the propensity to engage in R&D cooperation agreements with PROs. Fontana et al. (2006) find that participating in government-funded projects, positively affect the propensity for firms to collaborate with PROs, and Miotti and Sachwald (2003) and Segarra-Blasco and Arauzo-Carod (2008) find that public funds for innovation has a positive impact on the propensity to develop R&D cooperation, in particular with research institutions.

In light of the variables at firm and at industry levels identified, the following paragraph analyses the features of the Italian innovating companies and their propensity to get involved in PPPs during the years 2010-2012.

Table 12: Empirical contributions analyzing the determinants of firms' propensity to collaborate with external players

Level	***Factors***	***References***
Industry level	High-tech sectors and technological complexity	Caloghirou et al. (2003); Tether (2002); Veugelers and Cassiman (2005); Bayona et al. (2001); Miotti and Sachwald (2003); Dachs et al. (2008); Segarra-Blasco and Arauzo-Carod (2008); De Faria (2010); Lööf and Brostrom (2008); Miozzo and Dewick (2004); Veugelers and Cassiman (2005); Schartinger et al. (2002).

Firm level	Size	Belderbos et al. (2004); Fontana et al. (2006); Veugelers and Cassiman (2005); Lòpez, (2008); Fritsch and Lukas (2001); Negassi (2004); Miotti and Sachwald (2003); Bayona et al. (2001); Segarra-Blasco and Arauzo-Carod (2008); Fontana et al. (2006), Lööf and Brostrom (2008).
	Absorptive capacity and innovativeness	Abramovsky et al. (2005); Cassiman and Veugelers (2002); Bayona et al. (2001); Miotti and Sachwald (2003); De Faria et al. (2010); Dachs et al. (2008); Becker and Dietz (2004); Mowery et al. (1998); Segarra-Blasco and Arauzo-Carod (2008); Monjon and Waelbroeck (2003), Fontana et al. (2006).
	Role of MNC	Tether (2002); Belderbos et al. (2004); Segarra-Blasco and Arauzo-Carod (2008).
	Costs	Miotti and Sachwald (2003); Cassiman and Veugelers (2002); Belderbos et al. (2004).
	Risks	Cassiman and Veugelers (2002); Belderbos et al. (2004).
Regional/Country level	Public funds	Miotti and Sachwald (2003); Belderbos et al. (2004); Evangelista (2007); Segarra-Blasco and Arauzo-Carod (2008); Miotti and Sachwald (2003); Fontana et al. (2006); Segarra-Blasco and Arauzo-Carod (2008)

Source: authors' elaboration

3.2.2. The dataset

The dataset taken into account for the analysis is the file of anonymized microdata derived from the CIS 2010-2012[127], a harmonised survey conducted every two years across the EU by a national institute, mainly the statistical agency, which is coordinated and supported by Eurostat. The main purpose of the survey is to collect information regarding the size and sector in which the innovative enterprises operate, the type of innovation introduced, the expenditure for the introduction of these innovations, the main objectives of these innovation activities, public funding support and cooperation agreements. Moreover, it provides general information concerning the belonging to groups of enterprises, the revenues, the main economic activity and the number of employees. The concepts, methods and questionnaire have been developed by Eurostat in cooperation with the other European countries, on the basis of the Oslo Manual - second edition of 1997 and third edition of 2005. The data collected refer to enterprises with 10 employees or more active in the following NACE 2007 sectors:

[127] I were obliged to take into account the file of anonymized microdata related to the period 2010-2012, since the one related to the period 2012-2014 was not available yet.

- Mining support service activities (B09)
- Manufacturing (C10-C33)
- Electricity, gas steam and air conditioning supply (D35)
- Water supply, sewerage, waste management and remediation activities (E36;E39)
- Construction (F)
- Wholesale and retail trade; repair of motor vehicles and motorcycles (G)
- Transportation and storage (H)
- Information and Communication (J), expect for J59 (Motion picture, video and television programme production, sound recording and music publishing activities) and J60 (Programming and broadcasting activities)
- Financial and insurance activities (K)
- Professional, scientific and technical activities (M), except for the divisions M69, Legal and accounting activities, and M75, Veterinary activities.

The initial population was constituted by 163.347 enterprises; specific sampling methods adopted generated an initial sample equal to 35.000 enterprises; the total valid answers have been 18.697, equal to almost the 59% of the initial sample. The questionnaire contained the following information:

- General information about the enterprise
- Product (good or service) innovation
- Process innovation
- Ongoing or abandoned innovation activities for product and process innovations
- Activities and expenditures for product and process innovations
- Sources of information and co-operation for product and process innovation
- Competitiveness of the enterprise’s product and process innovations
- Organisational Innovation
- Marketing innovation
- Public sector procurement and innovation
- Strategies and obstacles for reaching the enterprise’s goals

The dataset is cross-sectional and not longitudinal; therefore it is not possible to examine the innovation performance of Italian firms taking into account time variations.

In line with the OECD classification of industries in terms of technological intensity, I decided to divide the enterprises in five main groups according to the sector (manufacturing and services) and technological intensity (high or low). Finally, five main categories have been identified, in accordance with the OECD classification for the technological intensity of industries: high-tech manufacturing, low-tech manufacturing, KIS; less KIS and other sectors[128]. Table 13 shows the categories identified.

Table 13: Classification of the industries in terms of technological intensity in line with the OECD

Category	Description	NACE CODE 2007
High-tech sectors (High and medium-high)	Manufacture of basic pharmaceutical products and pharmaceutical preparations; Manufacture of computer, electronic and optical products; Manufacture of chemicals and chemical products; Manufacture of electrical equipment; Manufacture of machinery and equipment n.e.c.; Manufacture of motor vehicles, trailers and semi-trailers; Manufacture of other transport equipment	C21; C26; C20; C27-C30
Low-tech sectors (Low and medium-low)	Manufacture of coke and refined petroleum products; Manufacture of rubber and plastic products; Manufacture of other non-metallic mineral products; Manufacture of basic metals; Manufacture of fabricated metals products, except machinery and equipment; Repair and installation of machinery and equipment; Manufacture of food products, beverages, tobacco products, textile, wearing apparel, leather and related products, wood and of products of wood, paper and paper products, printing and reproduction of recorded media; Manufacture of furniture; Other manufacturing	C19-C22-25;C33;C10-C18;C31-C32
Knowledge Intensive Services (KIS)	Water transport; Air transport; Telecommunications; computer programming, consultancy and related activities; Information service activities; Financial and insurance activities; Activities of head offices, management consultancy activities; Architectural and engineering activities, technical testing and analysis; Scientific research and development; Advertising and market research; Other professional, scientific and technical activities	H10-H51; J58-J63;K64-K66;M70-M74
Less KIS	Wholesale and retail trade; Repair of motor vehicles and motorcycles; Land transport and transport via pipelines; Warehousing and support activities for transportation; Postal and courier activities	G45-G47; H49; H52;H53
Others	Mining support service activities; Electricity, gas steam and air conditioning supply; Water collection, treatment and supply; Remediation activities and other waste management services; Construction of buildings, Civil engineering, specialized construction activities	B9;D35;E36;E39;F41-F43

Source: author's elaboration

General information about the sample

First of all, Table 14 and Table 15 show the distribution of the sample by sector and by size. The total 18.697 enterprises are distributed in the following sectors: the 6% of the total sample is in the high-tech sector, the 16% in the low-tech sector, the 13% is in the KIS, the 36% in the less KIS and the 29% in other sectors, which include the energy and the construction sectors. The sample division in terms of technological intensity shows that just a minority of firms, about the 19% of the total, operate in the high-tech manufacturing and KIS sectors, which are expected to be the most dynamic in terms of innovation activities; the remaining 81% of the total is involved in low-tech, less KIS and other sectors, expected to have a less

[128] To facilitate the presentation, I grouped the high and the medium-high technologies sector into high-tech manufacturing, low and medium-low technologies sector into low-tech sector; the category 'others' include energy services (B9; D,E) and construction (F41-F43).

dynamicity. Moreover, the data related to the size of the firms reveal that the majority of the enterprises involved are SMEs: the 71% of the total sample has a number of employees between 10 and 49, the 19% between 50 and 249 and the remaining 10%, 250 or more employees.

Taking into account the distribution of the sample, by size and sector (Figure 10), the most numerous enterprises are concentrated in the high-tech, low-tech and KIS sectors, with the less numerous enterprises concentrated in the less KIS and other sectors: the largest firms in terms of number of employees are in the high-tech sector, with the relatively highest percentage of firms belonging to the class of average number of employees equal or higher than 250 (34%), followed by the KIS (15%), the low-tech sector (14%), the less KIS (7%) and the other sectors (3%). Moreover, the relatively highest percentage of firms belonging to a class of average number of employees between 50 and 249 is in the high-tech (29%), followed by the low-tech (27%), KIS (24%), less KIS (17%) and others (14%). Finally the relatively highest percentage of firms belonging to a class of average number of employees between 10 and 49 is in other sectors (83%), followed by less KIS (76%), KIS (61%), low-tech (59%) and high-tech (37%).

Table 14: Distribution of the sample by sector

Sector	**Percentage**
High-tech	6%
Low-tech	16%
KIS	13%
Less KIS	36%
Others	29%
Total	100%

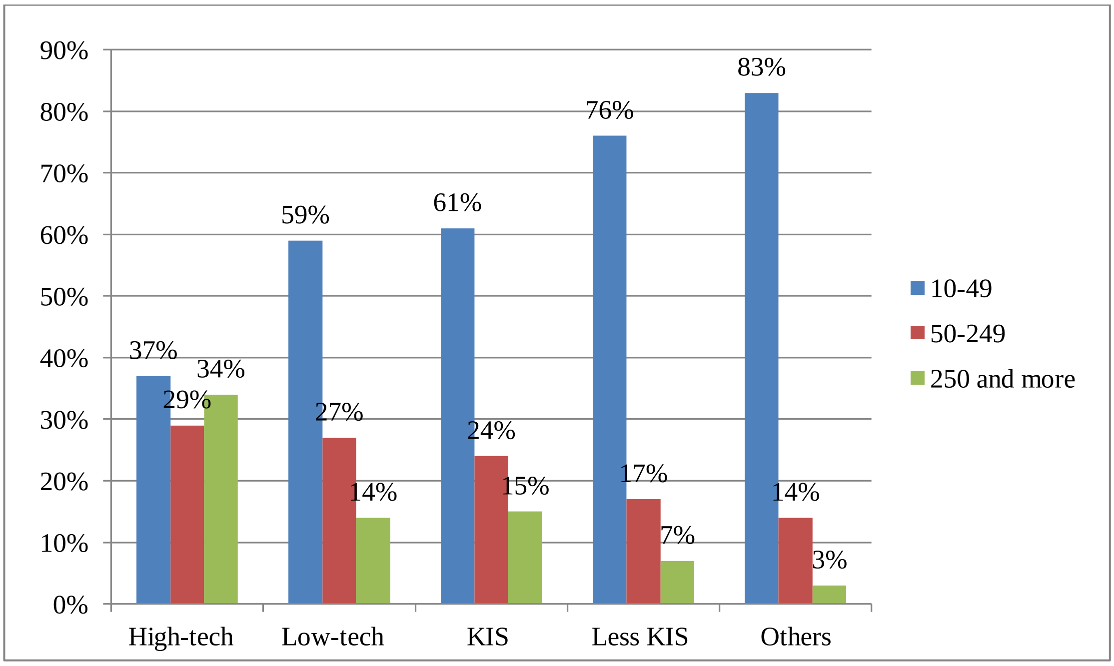
Source: author's elaboration on CIS 2012 data

Table 15: Distribution of the sample by class of employees

Class of employees 2012	**Percentage**
10-49	71%
50-249	19%
250 and more	10%
Total	100%

Source: author's elaboration on CIS 2012 data

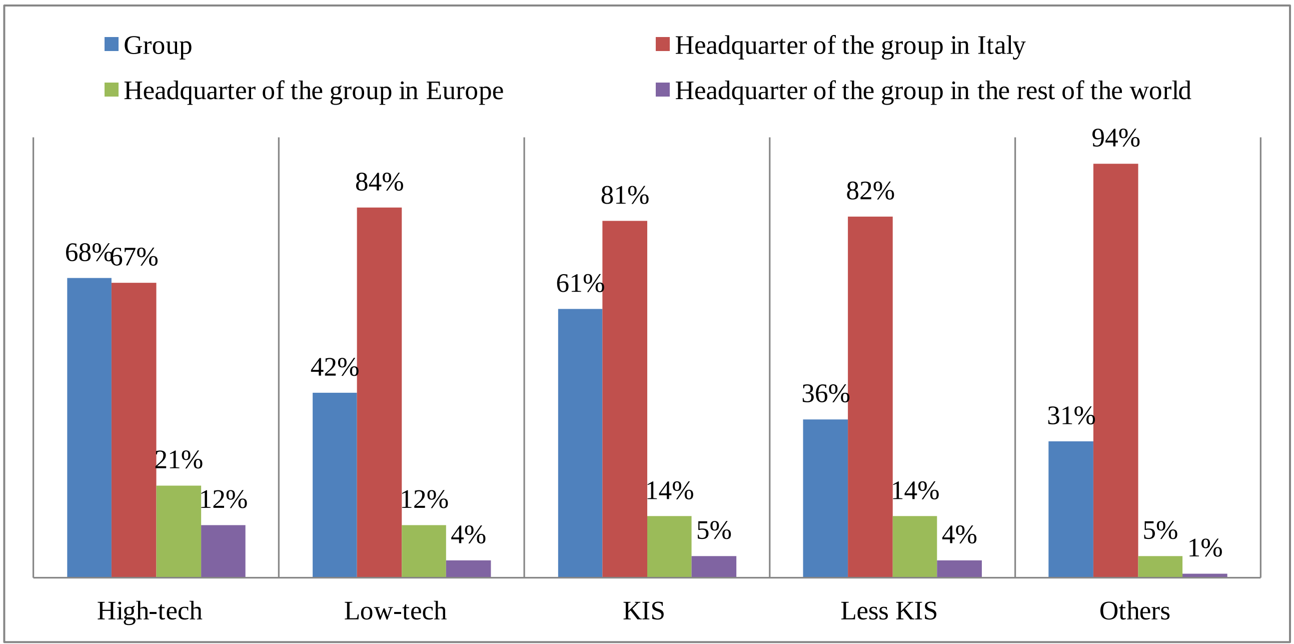
Figure 10: Distribution of the sample by size and sector



Source: author's elaboration on CIS 2012 data

Figure 11 shows the distribution of the sample by group and headquarter of the group. The 40% of the total enterprises belong to a group of enterprises. The relatively highest percentage of firms being part of a group belong to the high-tech and KIS sectors, with respectively the 68% and 61%, followed by the low-tech (42%), less KIS (36%) and others (31%). The 83% of the total sample belonging to a group is headquartered in Italy, the 12% in Europe and the remaining 4% in the rest of the world. The relatively highest percentage of firms belonging to a group with headquarter in Europe or in the rest of the world is in the high-tech sector (33%), followed by KIS (19%), less KIS (18%), low-tech (16%) and others (6%).

Figure 11: Distribution of the sample by group and headquarter of the group in 2012

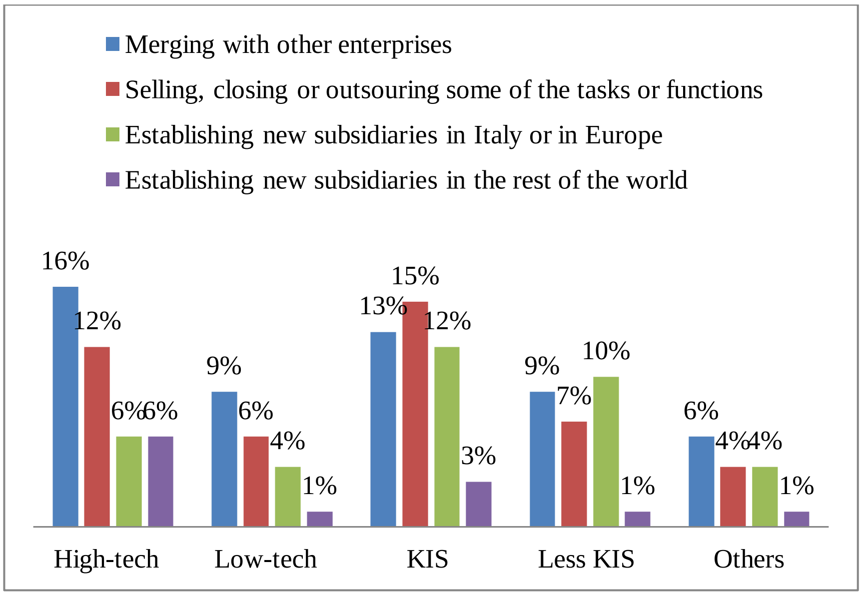


Source: author's elaboration on CIS 2012 data

As expected, the firms in the high-tech and in the KIS sectors, in which there is a significant influence of FMC, are the most dynamic in terms of operations concerning the internal organizations of the enterprises (fusion, outsourcing and establishment of new subsidiaries).

As shown in Figure 12, the relatively highest percentage of firms involved in operations regarding merging or taking over of other enterprises can be found in the high-tech and KIS sectors, with respectively the 16% and the 13%. For the other sectors these percentages are around the 6-9% A similar trend regards the enterprises involved in operations of selling, closing and outsourcing internal tasks or functions, with the relatively highest percentage in the KIS (15%) followed by the high-tech (12%), less KIS (7%), low-tech and others (respectively 6% and 4%). The operations of establishing new subsidiaries in Italy or in Europe have been taken mostly by firms in the KIS sector with a relative percentage of the 12%, followed by the less KIS (10%), high-tech (6%) and low-tech and others (4%). Similarly, operations of establishing new subsidiaries in the rest of the world have been taken mostly by firms in the high-tech (6%) followed by KIS (3%), low-tech and others (around 1%).

Figure 12: Distribution of the sample by sector and type of operations implemented in 2010-2012

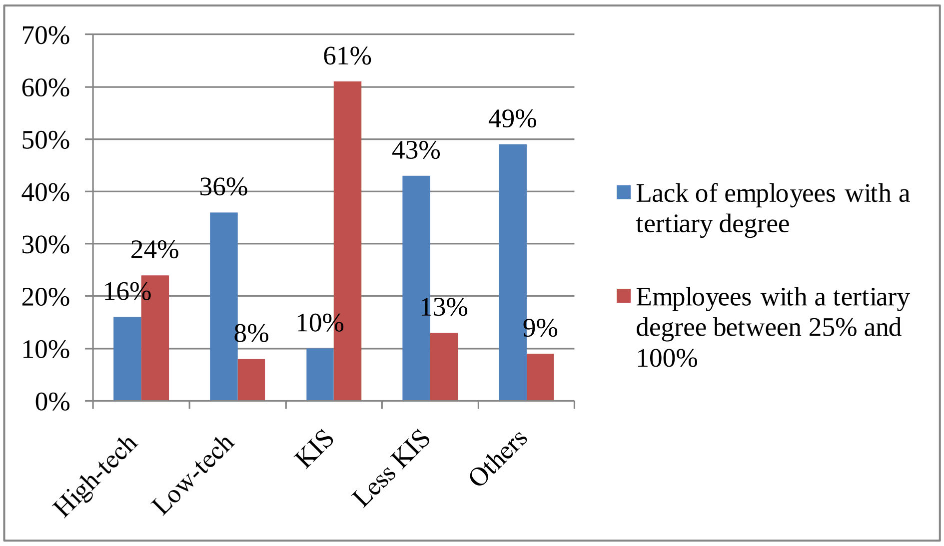


Source: author's elaboration on CIS 2012 data

Moreover, the firms in the high-tech and KIS sectors have employees with the relatively highest level of education. Figure 13 shows the distribution of the total firms by level of education of their employees[129] in 2012. First of all, a quite high percentage of the overall sample (38%) stated not to have any, with the relatively highest percentage in other sectors (49%), followed by less KIS (43%), low-tech (36%) high-tech (16%) and KIS (10%). Instead, the relatively highest percentage of firms having a percentage of employees with a tertiary degree between 25% and 100% is in the KIS sector (61%) followed by the high-tech (24%), less KIS (13%), low-tech (8%) and others (9%).

[129] The level of education of the employees is measured in terms of employees having one of the following certificates: bachelor or master degree issued after courses of 4-6 years (except those released by Academies, Conservatories and Institutes for Physical Education), including PhD degrees and post graduate schools.

Figure 13: Percentage of firms with employees having a tertiary degree by sector in 2012

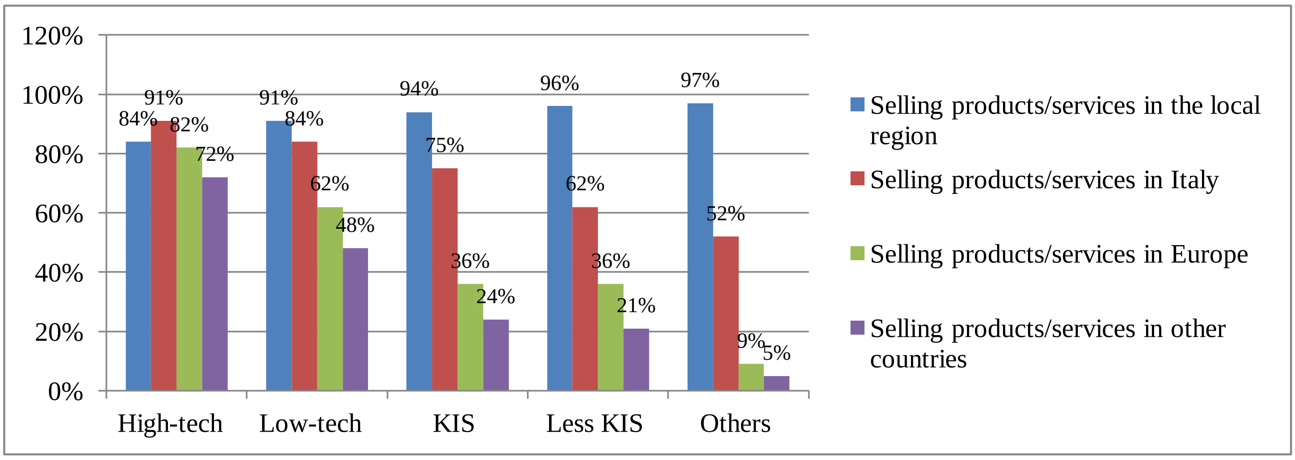


Source: author's elaboration on CIS 2012 data

Figure 14 shows the level of internationalization of the enterprises; data on the geographic markets on which enterprises sell their goods and/or services during 2010-2012, reveal that the most internationalized firms are in the manufacturing sector, both high-tech and low-tech.

First of all, taking into account the overall sample, the 94% of the total enterprises sell their goods or services locally, inside the region where the enterprise is located; the 66% of them sell in other regions of the country in which their enterprise is located; the 35% in a European country (EU member state, candidate EU and EFTA countries) and the 24% in other countries of the world. Taking into account the relative percentage of firms selling products/services in the country in Europe and in other countries, the relative highest concentration is in the high-tech (82% and 72%) followed by the low-tech (62% and 48%), KIS (36% and 24%), less KIS (36% and 21%) and other sectors (9% and 5%).

Figure 14: Distribution of the sample by level of internationalization in 2010-2012 by sector



Source: author's elaboration on CIS 2012 data

Goals, strategies and obstacles for innovative and non innovative countries

The analysis of the goals, strategies and obstacles considered very important by the Italian firms in comparison to other European countries taken into account in the CIS survey, suggests the substantial lack of a forward looking long-term strategy for innovation activities of the Italian firms.

As shown in Table 16, in Italy there are relatively high percentages of firms considering the decrease in costs and the increase in turnover, which may be considered closer to a short-term business strategy, as highly relevant, while the opposite trend regards the increase in market share and the increase in profit margins, which may be attributed to a more long-term business strategic approach.

Similarly, the analysis of the strategies considered very important by firms (Table 17) shows that the Italian firms are relatively not much interested in building alliances with other firms and institutions (7.5%) introducing new or significantly improved goods or services (26.2%), developing new markets in Europe (20.4%) and improving the marketing of goods and services (16.1%), while there is one of the relatively highest percentages of firms considering the reduction of costs of purchased and of in-house operations as highly important (respectively the 43.9% and the 48.4%). As for the major obstacles these firms perceive (Table 18), there are relatively high percentages of Italian firms considering strong price competition (55.1%), the lack of adequate finance (22.7%), the high cost of meeting government regulation and legal requirements (39.9%) and the lack of demand (41.5%) as highly relevant; similarly, there are relatively low percentages of firms considering the strong competition on product quality (12.7%), the lack of qualified personnel (5.1%), and innovation by competitors (3.8%) as highly significant obstacles.

Table 16: Goals considered highly relevant from innovative and non innovative firms in Italy, compared to other European countries involved in the CIS survey (percentages)

	Decrease in costs (highly relevant)	Increase in market share (highly relevant)	Increase in market share not relevant	Increase in profit margins (highly relevant)	Increase in turnover (highly relevant)
Germany	52.8	35.0	10.3	58.8	60.0
Italy	60.0	40.5	12.0	44.5	57.8
Netherlands	53.0	45.4	8.3	51.4	64.3
Poland	54.8	47.1	9.9	32.9	66.5
Portugal	75.7	55.8	5.8	53.0	72.9

Source: author's elaboration from Eurostat

Table 17: Strategies considered highly relevant from innovative and non innovative firms in Italy, compared to other European countries involved in the CIS survey (percentages)

	Building alliances	Reducing costs of purchased materials	Increasing flexibility and responsiveness of the organization	Reducing in-house costs of operations	Introducing new of significantly improved goods or services	Developing markets within Europe	Developing markets outside Europe	Improving the marketing of goods and services
Germany	9.9	41.5	33.3	45.9	38.4	20.1	14.2	23.1
France	11.3	40.4	43.8	50.3	34.1	28.1	19.9	24.0
Italy	7.5	43.9	33.1	48.4	26.2	20.4	19.9	16.1
Netherlands	15.2	30.3	44.8	42.0	32.5	29.4	17.6	25.4
Poland	10.2	36.6	31.4	37.4	33.3	23.5	14.3	22.8
Portugal	15.9	61.4	37.3	66.8	40.9	30.2	31.1	27.7

Source: author's elaboration from Eurostat

Table 18: Obstacles considered highly relevant from innovative and non-innovative firms in Italy, compared to other European countries involved in the CIS survey (percentages)

	High cost of access of new markets	Innovation by competitors	Dominant market share by competitors	Lack of adequate finance	Lack of Demand	Strong price competition	Lack of qualified personnel	Strong competition on product quality	High cost of meeting government regulation and legal requirements
Germany	14.6	6.0	15.5	10.0	15.6	61.2	18.8	27.4	19.5
Italy	17.3	3.8	14.1	22.7	41.5	55.1	5.1	12.7	39.9
Netherlands	7.8	4.3	11.4	13.6	25.5	42.6	8.6	20.6	11.9
Poland	17.8	13.0	17.3	20.2	23.5	48.6	9.7	26.1	19.5
Portugal	33.9	8.2	15.6	28.7	37.2	63.1	11.5	31.9	32.9

Source: author's elaboration from Eurostat

Confirming these trends, data from the CIS 2010-2012 reveal that the Italian firms have a relatively low propensity to collaborate with other firms and institutions in formal R&D agreements in comparison to the other European countries: only the 0.8% of the firms received funding from the 7th Framework Programme for Research and Innovation, following Poland (3.8%), Germany (3.7%), Belgium (3.6%), Greece (3.2%) and Finland (2.9%) and the other countries taken into account. The same trend may be observed concerning the propensity to cooperate with other group firms, competitors, private and public clients or customers and suppliers, covering the relatively lowest position in each case. Specifically, the level of cooperation with Universities is particularly low with only the 5.6% of the firms, following Finland (26.1%), Belgium (20.8%), UK (19.6%) and the other countries taken into account, for which this percentage is at least around 10% (Table 19). Moreover, only the 2.3% of the total consider this channel as the most valuable method vs. 7% in Germany.

Table 19: Cooperation with other firms and institutions by country during 2010-2012 (percentages)

Country/Cooperation indicator	Funding from the 7th Framework Programme	Co-operating with other group Firms	Co-operating with competitors	Co-operating with private clients or customer	Co-operating with public clients or customers	Co-operating with suppliers of equipment, materials, components or software	Co-operating with universities or other higher education institutions	Cooperation with universities or other higher education institutions as the most valuable method
European Union (28 countries)		12.6	8.7	.	.	18.4	13.0	.
Spain	2.2	8.5	6.7	9.2	3.0	13.2	10.3	4.2
France	2.2	15.0	7.4	11.9	4.0	20.8	11.6	3
Italy	0.8	3	3.9	4.3	1.9	6.8	5.6	2.3
Germany	3.7	7.4	4.7	8.7	3.9	9.8	14.3	7.0
UK	.	31.6	19.2	44.8	19.9	38.7	19.6	.
Belgium	3.6	26.4	14.4	24.4	7.1	40.1	20.8	.
Denmark	.	26.4	10.6	21.9	8.4	31.9	14.9	.
Greece	3.2	17.1	15.3	24.6	10.6	32.2	19.0	6.6
Netherlands	1.6	15.3	9.8	16.3	.	24.2	11.0	2.1
Poland	3.8	11.9	7.2	.	.	20.5	10.5	3.4
Portugal	2.2	6.9	5.5	10.3	4.7	12.9	9.5	2.8
Finland	2.9	20.3	25.9	30.4	22.1	30.7	26.1	.
Sweden	.	17.4	18.4	25.1	12.7	25.7	17.6	.
Norway	.	14.6	8.9	17	7.5	17.1	13.1	1.6

Source: author's elaboration on Eurostat data on CIS data

3.2.3. The model and the explanatory variables

I took inspiration for the econometric analysis from the work of Segarra-Blasco and Arauzo-Carod (2008). In line with their work, the model is estimated taking into account only the innovative firms, equal to 6.733. As already mentioned, the dataset is cross-sectional and not longitudinal; therefore it has not been possible to perform estimations taking into account time variations.

The response of interest is the collaboration with private and public partners, coded as a dichotomous variable which takes value 1 when the firm cooperates with other agents and 0 otherwise. Five types of cooperation agreements[130] are taken into account: cooperation with other firms or institutions, cooperation with other firms of the group, cooperation with customers and suppliers (vertical cooperation), cooperation with competitors (horizontal cooperation), cooperation with Universities (Italian and foreign Universities) and cooperation with public research centres.

The literature review has shown that firms' involvement in formal R&D cooperative agreements depends on some main industry characteristics, single firms' characteristics, type of R&D activity developed and origins of funds used in these activities. Specifically, the independent variables taken into account in the

[130] The cooperation for innovation activities with other firms and institutions is intended to be the active participation with other firms and institutions on innovation activities, in which both partners do not need to commercially benefit, excluding pure contracting out of work with no active cooperation.

model (listed in Table 20) are the following: industry characteristics, including belonging to a high-tech manufacturing sector; belonging to a KIS sector; the average of the industry's investments in innovation activities[131]; firms' specific variables, including size, belonging to a domestic group, to a foreign multinational, developing both product and process innovations, the deviation of the firm's investments in innovation activities from the industry average; the innovation sources, which include intramural R&D activities[132] and external R&D[133]; public funds, including regional, national and European funds[134].

In order to perform the analysis, a logistic model is adopted, particularly suitable to the case in which the response variable is a binary variable.

Let us assume that y_i is a dichotomous variable representing whether firm *i* collaborates with other firms and institutions or not; therefore, y_i follows a Bernoulli distribution with probability π_i, i.e. $y_i \sim$ Bernoulli (π_i), where π_i represents the probability that firm *i* cooperates with other firms and institutions.

Given the set of explanatory variables introduced in the model **X**, the probability that firm *i* cooperates with other firms and institutions is specified as follows:

$$\pi_i = \mathrm{P}(y_i=1|\mathbf{X})=\exp(\eta_i)\,/[1+\exp(\eta_i)]$$

where $log_e \frac{\pi_i}{1-\pi_i} = \eta_i = \boldsymbol{x}_i'\boldsymbol{\beta}$ is the linear predictor, with vector of explanatory variables $\boldsymbol{x}_i'$=($x_{i1}, x_{i2}, \ldots x_{ik}$) and vector of parameters $\boldsymbol{\beta}' =(\beta_0,\ \beta_1, \ldots\ \beta_k)$.

As also Segarra-Blasco and Arauzo-Carod (2008) underline, some explanatory variables taken into account in the model may be endogenous; in fact, while it is true that firms' propensity to cooperate during 2010-2012 may depend on firms' level of innovativeness, it may also be that the cooperation with other firms and institutions influences firms' innovativeness. Specifically, among the variables used, I identified three endogenous variables representing firms' innovative capacity: developing product and process innovations during 2010-2012 and performing intramural and external R&D activities during 2010-2012. The other variables accounting for firms' absorptive capacity, the average investments in innovation activities in the industry and firms' deviation from this average, may be considered exogenous variables

[131] Specifically, the total expenditures on innovation activities include the levels of expenditure in intramural R&D activities, external R&D activities, acquisition of machinery, equipment, software and buildings (excluding the expenditures on these items that are for R&D), acquisition of existing knowledge from other enterprises or organisations and all other innovation activities including design, training, marketing, and other relevant activities.

[132] Intramural R&D activities include R&D activities undertaken by the enterprise to create new knowledge or to solve scientific or technical problems (including software development in-house that meets this requirement).

[133] External R&D activities include R&D activities that the enterprise has contracted out to other enterprises (including other enterprises in the group) or to public or private research organisations.

[134] These sources of funds include the financial support via tax credits or deductions, grants, subsidised loans, and loan guarantees and exclude research and other innovation activities conducted entirely for the public sector (government owned organisations such as local, regional and national administrations and agencies, schools, hospitals, and government providers of services such as security, transport, housing, energy) under contract.

since they are referred to 2010[135], prior to the development of the formal cooperative agreement, that is between 2010-2012.

As Lòpez (2008) underlines, it is difficult to find perfectly exogenous instruments within the CIS, since every question is closely related and cross-section data are used. In line with the main purpose of this analysis, that is to understand the features of the Italian innovative firms involved in cooperative agreements, the following sections will present the results of the logistic model, without taking into account the problem of endogeneity. In Appendix 1a, I suggest a possible way to mitigate the problem.

Table 20: List of dependent and independent variables used in the model

	Variable	Description	Name of the variable
Industry variables	High-tech manufacturing	Takes the value 1 if the firm is in the high or medium-high-tech manufacturing industries and 0 otherwise.	hightech
	KIS	Takes the value 1 if the firm is in the KIS and 0 otherwise.	kis
	Industry investments in innovation activities	Mean of expenditure in innovation activities in 2010 divided by the revenue in 2010 by NACE 2007 code 2-digit.	rallmean
Firm variables	Medium Size (50-249 employees) or Large Size (more than 250 employees)	Takes value 1, if firm's employees in 2012 are in the class (10-49), 2, if in class (50-249) and 3 if in class (more than 250).	classemp
	Domestic group	Takes value 1 if the firm is part of a domestic firm grouping and 0 otherwise.	hoit
	Foreign Group	Takes value 1 if the firm is part of a foreign multinational and 0 otherwise.	hoextrait
	Product and process innovation	Takes value 1 if the firm made both product and process innovations in the period 2010-2012 and 0 otherwise.	innovprodproc
	Deviation from industry's investments in innovation activities	Deviation of the single firm's investments in innovation activities from the industry average.	rallimp
Type of R&D activities	Intramural R&D	Takes value 1 if the firm carried out internal R&D activities related to innovations made in the period	rrdin

[135] Data concerning firms' expenditure have been modified by ISTAT in order to protect firms' confidential information. For example, the level of the firm's expenditure in innovation activities in 2012 has been modified in the level of the firm's expenditure in innovation activities in 2010 on firm's total turnover.

		2010-2012 and 0 otherwise.	
	External R&D	Takes value 1 if the firm acquired external R&D services depending on innovative activities carried out in the period 2010-2012 and 0 otherwise.	rrdex
Public funds	Regional public funds	Takes value 1 if the firm accessed public resources of the local or autonomous administrations for innovative activities in the period 2010-2012 and 0 otherwise.	funloc
	National public funds	Takes value 1 if the firm accessed public resources of the state administration for innovative activities in the period 2010-2012 and 0 otherwise.	fungmt
	European public funds	Takes value 1 if the firm accessed public resources of the EU for innovative activities in the period 2010-2012 and 0 otherwise.	funeu
Cooperation Partners	All partners	Takes value 1 if the firm cooperated with firms or institutions during 2010-2012 and 0 otherwise.	co
	Group Firms	Takes value 1 if the firm cooperated with a group firm during 2010-2012 and 0 otherwise.	co1
	Customers and suppliers	Takes value 1 if the firm cooperated with clients and suppliers during 2010-2012 and 0 otherwise.	cooclifor
	Competitors	Takes value 1 if the firm cooperated with competitors during 2010-2012 and 0 otherwise.	co4
	Universities	Takes value 1 if the firm cooperated with Universities during 2010-2012 and 0 otherwise.	co6
	Public Research Centres	Takes the value 1 if the firm cooperated with public research centres during 2010-2012 and 0 otherwise.	co7

Source: author’s elaboration drawing on Segarra-Blasco and Arauzo-Carod (2008)

3.2.4. Descriptive statistics

Table 21 and Table 22 show the percentages of innovative firms by sector and by size. In line with the trends analyzed for the whole sample (3.2.2.), a minority of innovative firms (30%) belongs to the high-tech manufacturing and KIS, with nearly the 50% of the total sample composed by firms in the less KIS and other sectors (28% and 19%, respectively) and the 22% by firms in the low-tech manufacturing sector; as expected, the majority of firms belong to a class of employees between 10 and 49 (55%), the 26% to a class of employees between 50 and 249 and the 19% with employees equal or higher than 250. The high-tech sector has the relatively highest percentage of numerous firms, in terms of employees (41%), with respect to firms in the KIS (23%), as can be seen in Table 23.

Table 21: Share of innovative firms by sector in 2010-2012

Sector	Percentage
High-tech	12%
Low-Tech	22%
KIS	18%
Less KIS	28%
Others	19%
Total	100%

Source: author's elaboration on CIS 2012 data

Table 22: Share of innovative firms by size in 2010-2012

Class of employees 2012	Percentage
10-49	55%
50-249	26%
250 and more	19%
Total	100%

Source: author's elaboration on CIS 2012 data

Table 23: Share of innovative firms by sector and size in 2010-2012[136]

	Size (50-249)	%	Size (more than 250)	%	Total
High-tech	252	30%	345	41%	837

[136] These percentages must be read by row; for example, the percentage of firms in the high-tech sector belonging to a class of employees of (50-249) is of the 30%.

KIS	338	28%	286	23%	1229

As can be noticed from the shares of innovative firms by sector, size and belonging to a domestic or foreign group (Table 24), the sector with the highest concentration of large firms and of firms belonging to a foreign group is the high-tech sector (with respectively the 41% and the 23%), while the sector with the highest concentration of firms belonging to a domestic group is the KIS (55%).

Table 24: Share of innovative firms by sector, size and belonging to a group of firms in 2010-2012[137]

Variable	High-tech	Low-Tech	KIS	Less KIS	Others	Total
Large Firms	345	326	286	225	92	1274
	41%	22%	23%	12%	7%	19%
Domestic group	421	640	672	709	496	2.938
	50%	43%	55%	37%	38%	44%
Foreign group	204	131	154	195	39	723
	24%	9%	13%	10%	3%	11%
Total	**837**	**1.484**	**1.229**	**1.892**	**1.291**	**6.733**

Source: author's elaboration on CIS 2012 data

The analysis of the main indicators of innovation by sector (Table 25) shows the higher dynamicity of the manufacturing sector (high-tech and low-tech) and of the KIS sectors with respect to the others, in terms of innovation activity. The high-tech and low-tech manufacturing sectors are the ones with the higher concentration of firms having introduced product innovations during 2010-2012 (respectively the 83% and the 66%) and at least a process innovation[138] (respectively 74% and 77%). The same trend, but with lower percentages, characterizes the firms having introduced both a product and a process innovation during 2010-2012. As expected, the relatively highest percentage of firms introducing a service innovation is in the KIS sector (72%). The high-tech sector has the relatively highest percentage of firm introducing a radical new product or service[139] (62%) and relatively highest percentage of firms introducing radical new process innovation[140] (28%).

[137] These percentages must be read by column. For example, the percentage of large firms in the high-tech sector is of the 41%.

[138] Process innovations refer to: new or significantly improved methods of manufacturing or producing goods or services; new or significantly improved logistics, delivery or distribution methods for the inputs, goods or services; new or significantly improved supporting activities for the processes, such as maintenance systems or operations for purchasing, accounting, or computing.

[139] Radical new product or services refer to product and services new to the market in which the firm operates.

[140] Radical new processes refer to processes new to the market in which the firm operates.

A large majority of firms performing intramural R&D activities is in the high-tech and low-tech manufacturing sectors with, respectively, the 72% and 46%. A similar trend characterizes firms performing external R&D activities, with the 36% of the total sample in the high-tech sector, the 18% in the low-tech sector and 19% in the KIS. Moreover, there is a relatively high percentage of firms in the KIS sector (14%) with shares of R&D expenditure on turnover in 2010 between the 10% and the 90%, followed by firms in the high-tech sector (11%) and low-tech sector (8%). The relatively highest percentages of firms having access to regional public funds are in the high-tech sector (48%) and in the low-tech sector (25%) and the same trend characterizes the access to European public funds (12% of firms in the high-tech and 6% in the KIS).

Table 25: Main indicators of innovation by sector in 2010-2012[141]

Innovation Indicators/Sectors	High-tech	Low-tech	KIS	Less KIS	Others	Total
Product innovation	697	980	674	801	391	3.543
	83%	66%	55%	42%	30%	53%
At least one process innovation	618	1.150	842	1.281	932	4.823
	74%	77%	69%	68%	72%	72%
Product and process innovation	516	726	479	470	265	2.456
	62%	49%	39%	25%	21%	36%
Service innovation	287	454	880	957	586	3.164
	34%	31%	72%	51%	45%	47%
Incremental product or service innovation	462	699	724	868	507	3.260
	55%	47%	59%	46%	39%	48%
Radical new product or service innovation	521	620	554	676	331	2702
	62%	42%	45%	36%	26%	40%
Radical new process innovation	235	379	287	347	245	1493
	28%	26%	23%	18%	19%	22%
Intramural R&D activities	599	689	471	326	258	2.343
	72%	46%	38%	17%	20%	35%
External R&D activities	305	269	231	162	124	1.091
	36%	18%	19%	9%	10%	16%
The company has requested a patent	402	371	121	184	135	1.213
	48%	25%	10%	10%	10%	18%
Investments in innovation activities in 2010/turnover in 2010 between 10% and 90%	88	122	171	80	80	541
	11%	8%	14%	4%	6%	8%

141 These percentages must be read by column; for example the percentage of firms in the high-tech sector having introduced product innovations during 2010-2012 is of the 83%.

Regional public fund	216	341	190	273	192	1.212
	48%	25%	10%	10%	10%	18%
National public fund	180	180	139	95	57	651
	11%	8%	14%	4%	6%	8%
European public fund	98	67	79	58	38	340
	12%	5%	6%	3%	3%	5%
Total Number of Firms	**837**	**1.484**	**1.229**	**1.892**	**1.291**	**6.733**

Source: author's elaboration on CIS 2012 data

The analysis of the characteristics of cooperating vs. non cooperating innovative firms (Table 26 and 27) confirms the importance of a number of explanatory variables at industry and levels, which will be tested in the econometric analysis. In line with the main contributions analyzed on the topic, cooperating firms are characterized, with respect to non-cooperating firms, by the following features: a higher presence of firms in the high-tech manufacturing sector and in the KIS sector, having a higher R&D intensity, a larger size, belonging to a group, either domestic or foreign, with a higher concentration of firms introducing both product and process innovations, investing more than the industrial average in R&D activities, performing both intramural and external R&D activities and receiving public funds. Moreover, the same trends can be observed among the firms cooperating with Universities, with respect to the firms not cooperating Universities.

Table 26: Characteristics of innovative firms cooperating and not cooperating with other firms and institutions

	Cooperating firms	**Non-cooperating firms**
No. Observations	1.295	5.438
% of total obs. (on the total of innovative firms)	19%	81%
High-tech	21%[142]	10%
KIS	28%	16%
Average Industry investments in innovation activities	1%	0.7%
Small Size	38%	59%
Medium Size	24%	26%
Large Size	38%	14%
Domestic Group	59%	40%
Foreign Group	15%	9.7%
Product and Process Innovations	56%	32%
Deviation from average industry investments in innovation activities	1.4%	0.6%
Intramural R&D	61%	29%
External R&D	38%	11%

[142] This percentage refers to the share of firms in the high-tech sector cooperating with other players.

Regional Public funds	30%	15%
National Public Funds	21%	6.8%
European Public Funds	15%	2.6%

Source: author's elaboration on CIS data

Table 27: Characteristics of innovative firms cooperating and not cooperating with Universities

	Cooperating firms	**Non-cooperating firms**
No. Observations	638	6.095
% of total obs. (on the total of innovative firms)	9%	91%
High-tech	30%[143]	11%
KIS	29%	17%
Average Industry investments in innovation activities	1.7%	0.7%
Small Size	26%	58%
Medium Size	23%	26%
Large Size	51%	15%
Domestic Group	66%	41%
Foreign Group	16%	10%
Product and Process Innovations	62%	34%
Deviation from average industry investments in innovation activities	1.3%	0.7%
Intramural R&D	76%	30%
External R&D	53%	12%
Regional Public funds	40%	16%
National Public Funds	33%	7%
European Public Funds	25%	2.9%

Source: author's elaboration on CIS data

Finally, Table 28 shows the share of cooperative firms by sector and type of partner. As can be seen, the relatively highest percentage of firms cooperating with other firms and institutions can be found in the high-tech sector (33%) followed by firms in the KIS sector (29%), low-tech sector (16%), other sectors (14%) and less KIS (13%). The same trend concerns the cooperative agreements with Universities (23% are in the high-tech followed by 15% in the KIS sector) and with public research centres (11% in the high-tech sector and 10% in the KIS sector). Relatively high percentages of firms in the high-tech and KIS sectors, respectively the 17% and the 12%, cooperate with other firms of the group; the relatively highest percentage of firms cooperating with customers and suppliers is in the high-tech sector (7%) and the relatively highest percentages of firms cooperating with competitors are in the high-tech manufacturing and KIS sectors, respectively the 12% and the 10%.

[143] For example this percentage refers to the share of cooperative firms in the high-tech sector.

Table 28: Share of cooperative firms in 2010-2012 by type of partner and sector[144]

	All Firms		**High-Tech**		**Low-Tech**		**KIS**		**Less KIS**		**Others**	
Other firms and institutions	1.295	19%	277	33%	242	16%	360	29%	241	13%	175	14%
Other firms of the group	479	7%	146	17%	73	5%	148	12%	71	4%	41	3%
Customers and Suppliers	193	3%	62	7%	48	3%	44	4%	20	1%	19	1%
Competitors or other enterprises in your sector	394	6%	104	12%	71	5%	128	10%	50	3%	41	3%
Universities or other higher education institutions	638	9%	193	23%	127	9%	185	15%	59	3%	74	6%
Public research institutes	91	1%	91	11%	52	4%	121	10%	39	2%	41	3%
Number of Firms	**6.733**		**837**		**1.484**		**1.229**		**1.892**		**1.291**	

Source: author's elaboration on CIS 2012 data

Table 29 shows the share of firms cooperating with Italian and foreign Universities by sector in 2010-2012; as can be seen, the relatively highest percentages of firms cooperating with Italian Universities are in the high-tech manufacturing sector (22%), followed by firms in the KIS (15%); the same trend characterizes the share of firms cooperating with foreign Universities, with, respectively, the 6% in the high-tech and the 3% in the KIS.

[144] These percentages must be read by column. For example, the percentage of firms cooperating with other firms and institutions regardless of the sector is of the 19%.

Table 29: Share of firms cooperating with Universities (Italian and foreign) by sector in 2010-2012[145]

	All sectors	%	High-tech	%	Low-Tech	%	KIS	%	Less KIS	%	Others	%
Universities												
Italy	615	9%	181	22%	122	8%	182	15%	57	3%	73	6%
Foreign	135	2%	54	6%	19	1%	42	3%	9	0%	11	1%
Total	**6.733**		**837**		**1.484**		**1.229**		**1.892**		**1.291**	

Source: author's elaboration on CIS 2012 data

3.2.5. Results of the analyses

3.2.5.1. The propensity to cooperate with external partners

Table 30 and Table 31 show, respectively, the coefficients and the marginal effects[146] resulting from the logit model estimating the propensity of Italian firms to cooperate with other firms and institutions[147], given the set of explanatory variables selected. Table 32 summarizes the main results.

Taking into account the industry characteristics, the results show that belonging to a high-technological sector is positively correlated with the probability to participate to formal cooperation agreements with other firms and institutions. This result is in line with Caloghirou et al. (2003), Veugelers and Cassiman (2005), Bayona et al. (2001), Miotti and Sachwald (2003), Dachs et al. (2008), Segarra-Blasco and Arauzo-Carod (2008) and De Faria et al. (2010).

Moreover, this result is stronger for firms belonging to the service sector in comparison to firms belonging to the manufacturing sector. In fact, belonging to a KIS sector is positively correlated to the engagement in cooperative agreements with all partners in general, group firms, competitors, Universities and public research centres (significant at 1%), with a relatively high average marginal effect concerning the cooperation with other firms of the group; this result may be explained by the fact that there is a high concentration of firms in the KIS sector belonging to a group of firms (68%), as shown in Table 24.

On the other hand, belonging to a high-tech manufacturing sector is positively correlated only with the probability to cooperate with other group firms (significant at 10%), given the high concentration of firms belonging to a group (74%), and with Universities (significant at 5%). For the other partners (customers and suppliers, competitors and public research centres), no statistically significant results have been found. As shown in Appendix 1b, the coefficients accounting for the high-tech sector looses statistical

[145] These percentages must be read by column. For example, the percentage of firms cooperating with Italian Universities regardless of the sector is of the 9%.
[146] The marginal effects have been obtained from the calculation of the Average Marginal Effects (AMEs).
[147] The tables are a summary of the results obtained for each type of cooperating partner, adding and removing variables, in order to observe the effects' changes. The tables for each partner taken into account may be found in Appendix 1b.

significance when adding the variables related to performing intramural and external R&D activities; this result may be explained by the fact that there is a relatively high concentration of firms in the high-tech manufacturing sector performing both intramural R&D activities (72%) and implementing external R&D activities (36%), as can be seen in Table 25.

These results are partially in line with those of Segarra-Blasco and Arauzo-Carod (2008), who found statistically significant results for a higher propensity of firms in the KIS to be involved in cooperative agreements with all the partners taken into account, whereas for firms belonging to the high-tech manufacturing sector the results are statistically significant for the cooperation with competitors, Universities and public research centres.

Belonging to a sector with high levels of investments in innovation activities is positively correlated only with the involvement in cooperative agreements with Universities (significant at 1%). This result is in contrast to that of Segarra-Blasco and Arauzo-Carod (2008), who found statistically significant results (at 1% level) for a higher propensity of these firms to cooperate with all types of players; this may be explained by the fact that only the 8% of the total sample have levels of investments in innovation activities different from 0, as shown in Table 25 and from the fact that the authors have considered the levels of expenditure in R&D activities, while the index I took into account includes also levels of expenditure in other innovation activities, like design activities.

As for firms' specific characteristics, the following results emerge.

The analysis reveals that the size of the firm is an important factor explaining firms' involvement in cooperative agreements and this is in line with some of the main works reviewed on the topic: Belderbos et al. (2004), Fontana et al. (2006), Veugelers and Cassiman (2005), Lòpez (2008), Fritsch and Lukas (2001), Negassi (2004), Miotti and Sachwald (2003), Bayona et al. (2001) and Segarra-Blasco and Arauzo-Carod (2008). Whereas no statistical significant result has been found for medium sized firms (with employees between 50 and 249), belonging to large firms (with more than 250 employees) is positively correlated with the probability to participate to cooperative agreements with each actor taken into account and this result is highly significant (at 1%) for each actor, except for customers and suppliers and competitors (significant at 5%). The marginal effect is particularly high concerning the cooperation with Universities and group firms. This result may be explained by the fact the large size is highly correlated with the high-tech sector, where there is a high concentration of firms cooperating with Universities and group firms.

Being part of a group of firms is generally associated to a higher propensity to be involved in cooperative agreements with external partners (Tether, 2002; Belderbos et al., 2004; Segarra-Blasco and Arauzo-Carod, 2008). My results show that belonging to a domestic group is positively correlated with the involvement in cooperative agreements with competitors and Universities (significant at 1%) and public research centres (significant at 5%). This result may be explained by the fact there is a relatively high percentage of firms in the KIS sector, which belongs to a domestic group (55%), as shown in Table 24, which revealed to cooperate with competitors, Universities and public research centres. Moreover, I did not found statistically significant results regarding cooperation with other partners for firms belonging to a foreign group, except for research centres, which, however, looses statistical significance when calculating the average marginal effect. A possible explanation of this result may be that cooperation with external partners is more likely to occur for firms of multinationals headquartered in the country of origin.

However, as shown in table 30, firms belonging to a domestic group are less likely to cooperate with firms of the same group with respect to firms belonging to a foreign group (significant at 1%). This result is partially in line with those of Segarra-Blasco and Arauzo-Carod (2008) who have found strong statistically significant results for firms belonging to a foreign multinational cooperating with group firms (significant at 1%), with respect to cooperation with customers and suppliers (significant at 10%) and competitors (significant at 5%).

The literature review has shown that the level of absorptive capacity and of innovativeness is positively correlated to the firm's involvement in formal cooperative relationships with other partners (Segarra-Blasco and Arauzo-Carod, 2008; Abramovsky et al. 2005; Cassiman and Veugelers, 2002; Bayona et al. 2001, Miotti and Sachwald, 2003; De Faria et al. 2010; Dachs et al. 2008; Becker and Dietz, 2004; Mowery et al., 1998). My analysis confirms the results of the literature, showing that highly innovative companies, which have introduced both product and a least a process innovation are positively correlated to the engagement in cooperative agreements with each actor taken into account (significant at 1%). This result is in line with Segarra-Blasco and Arauzo-Carod (2008). Moreover, firms investing in innovation activities more than the industry average tend to be involved in cooperative agreements with group firms (significant at 1%), competitors and public research centres (significant at 10%). This result may be explained by the fact that the KIS sector, which is likely to cooperate more with group firms, competitors and Universities has also the relatively highest level of investments in innovation activities (14%), as can be seen in Table 25.

As for the innovation sources, firms performing intramural and external R&D activities are positively correlated to the participation to cooperation agreements with each actor taken into account, including group firms (significant at 5%), clients and suppliers, competitors, Universities and public research centres (significant at 1%). This result is in line with Bayona et al. (2001) and Segarra-Blasco and Arauzo-Carod (2008) and may be explained by the fact that firms performing internal R&D activities may need to integrate the internal knowledge sources with external ones. The probabilities are relatively higher regarding cooperation with Universities.

The reception of public funds is associated to a higher involvement in cooperative agreements with external partners according to Veugelers and Cassiman (2005), Miotti and Sachwald (2003) and Segarra-Blasco and Arauzo and Carod (2008) and contrary to Belderbos et al. (2004) and Evangelista (2007). In general, I found that firms receiving regional, national and European funds have a higher probability to get involved in cooperation agreements with other partners. Specifically, firms receiving regional public funds tend to participate more to cooperation agreements with group firms (significant at 10%), competitors, Universities and public research centres (significant at 1%) with a higher marginal effect in the case of cooperation with Universities and public research centres. This result partially confirms the analysis of

Segarra-Blasco and Arauzo-Carod (2008) who found statistically significant results only concerning the cooperation with Universities and public research centres. Moreover, firms receiving national public support for innovation activities tend to cooperate with Universities and public research centres (significant at 1%) and group firms and competitors (significant at 10%). The probability is higher concerning the propensity to cooperate with Universities and public research centres. This result confirms the analysis of Segarra-Blasco and Arauzo-Carod (2008) who found stronger result concerning the cooperation with group firms and competitors (significant at 1%). Finally, the reception of European public funds is of course strongly correlated to the participation to cooperative agreements with other partners, particularly with Universities, public research centres, competitors and group firms (significant at 1% level). The marginal effect is particularly high for the propensity to collaborate with Universities and group firms. This result is in line with Segarra-Blasco and Arauzo-Carod (2008).

Table 30: Coefficients of the logit model for cooperation with other firms and institutions

	All partners	**Group firms**	**Clients and Suppliers**	**Competitors**	**Universities**	**Public research centres**
	b/se	b/se	b/se	b/se	b/se	b/se
Industry variables						
High-tech	0.064	0.254***	0.325***	-0.180	0.283**	0.073
	(0.104)	(0.142)	(0.194)	(0.158)	(0.132)	(0.172)
KIS	0.627*	0.728*	0.263	0.630*	0.670*	0.970*
	(0.093)	(0.141)	(0.220)	(0.134)	(0.134)	(0.164)
Average industry investments in innovation activities	4.152***	0.667	2.776	0.164	8.535*	2.256
	(2.506)	(3.538)	(4.546)	(3.099)	(2.922)	(3.288)
Firm variables						
Size (50-249)	-0.108	-0.011	0.072	-0.082	0.138	0.087
	(0.092)	(0.162)	(0.220)	(0.140)	(0.141)	(0.177)
Size (more than 250)	0.550*	0.878*	0.515**	0.390*	1.001*	0.549*
	(0.100)	(0.149)	(0.226)	(0.149)	(0.142)	(0.183)
Domestic Group	0.561*	-0.409*	0.312	0.352*	0.602*	0.414**
	(0.087)	(0.126)	(0.215)	(0.132)	(0.138)	(0.174)
Foreign Group	0.445*	.	0.404	0.004	0.274	0.389***
	(0.126)	.	(0.273)	(0.198)	(0.186)	(0.230)
Product and Process Innovations	0.497*	0.872*	0.733*	0.407*	0.436*	0.492*
	(0.073)	(0.117)	(0.169)	(0.109)	(0.104)	(0.134)
Deviation from R&D industry average	0.878**	1.906*	0.839	1.001***	0.118	1.056***
	(0.420)	(0.629)	(0.775)	(0.524)	(0.594)	(0.615)
Innovation Sources						
Intramural R&D	0.578*	0.298**	1.002*	0.530*	0.925*	0.666*
	(0.078)	(0.126)	(0.194)	(0.120)	(0.116)	(0.151)
External R&D	0.910*	0.727*	0.554*	0.403*	1.170*	1.094*

	(0.083)	(0.118)	(0.167)	(0.122)	(0.104)	(0.133)
Public Funds						
Local public funds	0.575*	0.241***	0.159	0.446*	0.829*	0.693*
	(0.085)	(0.136)	(0.180)	(0.121)	(0.112)	(0.139)
National public funds	0.342*	0.264***	0.121	0.259***	0.545*	0.824*
	(0.104)	(0.141)	(0.198)	(0.144)	(0.124)	(0.146)
European public funds	1.020*	0.961*	0.714*	1.198*	1.353*	1.431*
	(0.135)	(0.170)	(0.220)	(0.155)	(0.149)	(0.165)
Model	-2.983*	-3.292*	-5.307*	-3.836*	-4.800*	-5.194*
	(0.079)	(0.182)	(0.210)	(0.118)	(0.142)	(0.177)
N	6733	3661	6733	6733	6733	6733

Source: author's elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

Table 31: Average marginal effects of the logit model for cooperation with other firms and institutions

	All partners	Group firms	Clients and Suppliers	Competitors	Universities	Public Research Centres
Industry variables						
	b/se	b/se	b/se	b/se	b/se	b/se
High-tech	0.008	0.025***	0.009	-0.010	0.018**	0.003
	(0.013)	(0.015)	(0.006)	(0.008)	(0.009)	(0.007)
KIS	0.085*	0.076*	0.007	0.041*	0.045*	0.045*
	(0.014)	(0.016)	(0.007)	(0.010)	(0.010)	(0.009)
Average industry investments in innovation activities	0.516***	0.063	0.073	0.009	0.524*	0.087
	(0.311)	(0.336)	(0.119)	(0.175)	(0.179)	(0.126)
Firm variables						
Size (50-249)	-0.013	-0.001	0.002	-0.004	0.007	0.003
	(0.011)	(0.012)	(0.005)	(0.007)	(0.008)	(0.006)
Size (more than 250)	0.076*	0.089*	0.014**	0.024**	0.069*	0.022*
	(0.015)	(0.014)	(0.006)	(0.010)	(0.010)	(0.008)
Domestic Group	0.071*	.	0.008	0.020*	0.037*	0.016**
	(0.011)	.	(0.006)	(0.008)	(0.008)	(0.007)
Foreign Group	0.060*	.	0.012	0.000	0.018	0.016
	(0.018)	.	(0.009)	(0.011)	(0.013)	(0.011)
Product and Process Innovations	0.064*	0.084*	0.019*	0.023*	0.027*	0.019*
	(0.010)	(0.011)	(0.004)	(0.006)	(0.007)	(0.005)
Deviation from R&D industry average	0.109**	0.181*	0.022	0.057***	0.007	0.041***
	(0.052)	(0.060)	(0.020)	(0.030)	(0.036)	(0.024)
Innovation Sources						
Intramural R&D	0.076*	0.028**	0.025*	0.031*	0.058*	0.025*
	(0.011)	(0.012)	(0.005)	(0.007)	(0.007)	(0.006)
External R&D	0.135*	0.077*	0.016*	0.025*	0.088*	0.050*

	(0.014)	(0.014)	(0.005)	(0.008)	(0.009)	(0.007)
Public Funds						
Local public funds	0.079*	0.024***	0.004	0.028*	0.059*	0.030*
	(0.013)	(0.014)	(0.005)	(0.008)	(0.009)	(0.007)
National public funds	0.046*	0.027***	0.003	0.016***	0.038*	0.039*
	(0.015)	(0.015)	(0.006)	(0.009)	(0.010)	(0.008)
European public funds	0.157*	0.115*	0.024*	0.101*	0.116*	0.085*
	(0.024)	(0.025)	(0.009)	(0.018)	(0.017)	(0.014)
N	6733	3661	6733	6733	6733	6733

Source: author's elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

Table 32: Propensity to cooperate with other firms and institutions (main results)

Explanatory variables	Main results
Industry variables	Belonging to a high-tech manufacturing sector is positively correlated to the cooperation with group firms and Universities.
	Belonging to a KIS is positively correlated to the cooperation with group firms, competitors, Universities and public research centres. The relatively higher marginal effects concern cooperation with group firms.
	Belonging to sectors with a higher level of investments in innovation activities is positively correlated with cooperation to Universities.
Firm variables	Belonging to a large company is positively correlated to the cooperation with group firms, customers and suppliers, competitors, Universities and public research centres. The relatively higher marginal effects concern cooperation with group firms and Universities.
	Belonging to a domestic group is positively correlated to the cooperation with competitors, Universities and public research centres; however, firms belonging to a domestic group have a lower propensity to cooperate with group firms with respect to firms belonging to a foreign group. The relatively higher marginal effects concern cooperation with Universities.
	No statistically significant results are found for firms belonging to a foreign group.
	Being highly innovative in terms of both product and process innovations is positively correlated to the cooperation with group firms, clients and suppliers, competitors, Universities and public research centres. The relatively higher marginal effects concern cooperation with group firms.
	Investing more than the industry average in innovation activities is positively correlated to the cooperation with group firms, competitors and public research centres. The relatively higher marginal effects concern the cooperation with group firms.
Innovation Sources	Performing intramural R&D activities is positively correlated to the involvement in cooperation projects with group firms, customers and suppliers, competitors, Universities and public research centres. The relatively higher marginal effects concern the cooperation with Universities.
	Performing external R&D activities is positively correlated to the involvement in cooperation projects with group firms, customers and suppliers, competitors, Universities and public research centres. The relatively higher marginal effects concern cooperation

	with Universities.
Public funds	Receiving regional public funding is positively correlated to the cooperation with group firms, competitors, Universities and public research centres. The relatively higher marginal effects concern cooperation with Universities.
	Receiving national public funding is positively correlated to the cooperation with group firms, competitors, Universities and public research centres. The relatively higher marginal effects concern cooperation with group firms.
	Receiving European public funding is positively correlated with cooperation with group firms, customers and suppliers, competitors, Universities and public research centres. The relatively higher marginal effects concern the cooperation with Universities and group firms.

Source; author's elaboration

3.2.5.2. The propensity to cooperate with Italian and foreign Universities

Table 33 and 34 show, respectively, the coefficients and the average marginal effects resulting from the logit model applied to estimate the propensity of Italian firms to cooperate with Italian and foreign Universities[148]. Table 35 summarizes the main results.

The literature review showed that the sector is a significant variable affecting firms' propensity to be engaged in formal cooperative agreements with Universities (Lööf and Brostrom, 2008; Miozzo and Dewick, 2004, Veugelers and Cassiman, 2005, Schartinger et al. 2002; Segarra-Blasco and Arauzo-Carod, 2008). My results show that belonging to high-tech manufacturing sectors is positively correlated to the propensity to cooperate with both Italian (significant at 10%) and foreign Universities (significant at 10% in Model 1 and at 5% in Model 2), also taking into account vertical and horizontal cooperation. The marginal effect does not vary much when taking into account also the cooperation variables, meaning that the high-tech sector is confirmed to be a significant variable explaining the propensity to cooperate with Italian and foreign Universities. This result may be explained by the fact that (see Table 24) there is a relatively high concentration of firms in the high-tech manufacturing sector belonging to a foreign group (24%), so that it may be assumed that the cooperation with foreign Universities is facilitated. This result is not in line with Segarra-Blasco and Arauzo-Carod (2008) who did not find statistically significant results for the cooperation with foreign Universities, probably due to the fact that they took into account data related to the period 1998-2000, when the internationalization process was less developed that it is today.

Whereas these authors found that firms in the KIS sector are more likely to cooperate with both national and foreign Universities, I found statistically significant results only concerning the cooperation with Italian Universities. This result may be explained by the fact that (see Table 24), there is a high concentration in the KIS sector of firms belonging to a domestic group (55%), while there is a relatively low

[148] The table is a summary of the results obtained for each type of collaborative partner, adding or removing variables, in order to observe effects' changes. The tables for each partner taken into account may be found in Appendix 1b.

percentage of firms belonging to a foreign group (13%). These results are in line with the ones of Segarra-Blasco and Arauzo-Carod (2008).

Concerning firm variables, in line with the literature review (Fontana et al. 2006; Lööf and Brostrom, 2008; Segarra-Blasco and Arauzo-Carod, 2008), my results confirm that size is an important determinant explaining firms' development of cooperation partnerships with Universities. This result is highly significant (at 1% level) for cooperation with Italian Universities in both cases; regarding the propensity to cooperate with foreign Universities, this variable looses statistical significance when taking into account also the cooperation with other partners.

Belonging to a domestic group is positively correlated to the cooperation with both Italian and foreign Universities and this result is highly significant (at 1% level); however, the marginal effect decreases slightly when taking into account also the cooperation variables. This result is partially in line with the ones of Segarra-Blasco and Arauzo and Carod (2008), who did not found statistically significant results concerning the cooperation with foreign Universities. On the contrary, firms belonging to a foreign group are more likely to develop partnerships with foreign Universities (significant at 10%) but this result is not statistically significant concerning the cooperation with Italian Universities. This result may be explained by the fact that cooperation agreements are usually decided at the firm's headquarters and therefore, are more likely to be developed with Universities which are located geographically closer to the group. However, this result is not in line with the ones of Segarra-Blasco and Arauzo-Carod (2008), who did not find statistically significant results for cooperation with neither national nor foreign Universities.

The level of firm's innovativeness is positively correlated to firms' propensity to cooperate with Universities, according to many contributions (Monjon and Waelbroeck, 2003; Fontana et al. 2006; Segarra-Blasco and Arauzo-Carod, 2008). My results show that firms introducing both products and process innovations are positively correlated to the involvement in partnerships with both Italian and foreign Universities (significant at 1%), but in the latter case, the marginal effects are no longer statistically significant when taking into account also the cooperation variables. Segarra-Blasco and Arauzo-Carod (2008) found statistically significant results (at 5%) only regarding the cooperation with national Universities. No statistically significant results are obtained when measuring the marginal effect of the variable accounting for the firm's deviation from the industrial average investments in innovation activities.

Moreover, firms performing intramural R&D activities are associated to a higher probability to get involved in formal agreements with both Italian and foreign Universities (significant at 1% and 5%); this result is in line with Segarra-Blasco and Arauzo-Carod (2008) except when taking into account the cooperation variables, estimating the cooperation with the foreign Universities. Similarly, firms performing external R&D activities are positively correlated with the engagement in formal agreements with both Italian and foreign Universities (significant at 1% and 10%), even if the marginal effects decrease significantly when taking into account the cooperation variables. This result is in line with Segarra-Blasco and Arauzo-Carod (2008) except for the case of formal collaborations with foreign Universities.

According to the literature review, firms receiving public funds are more likely to cooperate with Universities (Miotti and Sachwald, 2003; Fontana et al. 2006; Segarra-Blasco and Arauzo-Carod, 2008). My analysis confirms that firms receiving regional and national public funds are more likely to cooperate with both Italian and foreign Universities, but this effect is stronger in the former case; in the latter case, the effect is not statistically significant, when taking into account also the variables accounting for vertical and horizontal cooperation. This means that what matters for the cooperation with Italian and foreign Universities is not the reception of financial aids but the cooperation with other partners. These results are partially in line with those of Segarra-Blasco and Arauzo-Carod (2008), except for the collaboration with foreign Universities.

Finally, the reception of European public funds is obviously particularly important for the development of research partnerships with both Italian and foreign Universities, even if the correlation is weaker when taking into account also variables accounting for cooperation with other partners. This trend confirms the results of Segarra-Blasco and Arauzo-Carod (2008).

Concerning the variables representing cooperation with customers and suppliers, competitors and public research centres, the following considerations may be done. There is a positive correlation between the cooperation with customers and suppliers, competitors and public research centres and the probability of being engaged in cooperative agreements with both Italian and foreign Universities (significant at 1%), with a higher probability in the former case. This result is partially similar to the one of Segarra-Blasco and Arauzo-Carod (2008), except for cooperation agreements with competitors, which I found to be statistically significant in both cooperation with Italian and foreign Universities. This result may be explained by the fact that cooperation with Universities occurs often in the context of research partnerships which include also other firms, customers and suppliers, competitors and public research centres.

Table 33: Coefficients of the logit model for cooperation with Italian and foreign Universities

	Italian Universities		**Foreign Universities**	
	Model 1	**Model 2**	**Model 1**	**Model 2**
Industry variables	b/se	b/se	b/se	b/se
High-tech	0.231***	0.293***	0.458***	0.610**
	(0.134)	(0.157)	(0.252)	(0.283)
KIS	0.685*	0.402**	0.507***	0.333
	(0.135)	(0.158)	(0.303)	(0.329)
Average industry investments in innovation activities	8.276*	9.362*	12.988*	13.611*
	(2.924)	(3.535)	(4.431)	(4.952)
Firm variables				
Size (50-249)	0.060	0.035	0.242	0.183
	(0.143)	(0.166)	(0.314)	(0.343)
Size (more than 250)	0.985*	0.983*	0.820*	0.481
	(0.143)	(0.166)	(0.309)	(0.339)

Domestic Group	0.580*	0.541*	0.972*	0.940**
	(0.139)	(0.160)	(0.349)	(0.381)
Foreign Group	0.148	0.009	0.877**	0.990**
	(0.191)	(0.222)	(0.409)	(0.447)
Product and Process Innovations	0.397*	0.262**	0.647*	0.339
	(0.105)	(0.122)	(0.224)	(0.245)
Deviation from R&D industry average	0.195	-0.568	0.550	-0.926
	(0.590)	(0.827)	(0.922)	(1.001)
Innovation Sources				
Intramural R&D	0.933*	0.809*	1.057*	0.743**
	(0.117)	(0.135)	(0.303)	(0.324)
External R&D	1.193*	1.016*	0.737*	0.445***
	(0.105)	(0.125)	(0.209)	(0.235)
Public Funds				
Local public funds	0.809*	0.697*	0.473**	0.305
	(0.113)	(0.133)	(0.218)	(0.239)
National public funds	0.582*	0.335**	0.480**	0.042
	(0.124)	(0.151)	(0.226)	(0.257)
European public funds	1.218*	0.553*	2.110*	1.575*
	(0.151)	(0.196)	(0.222)	(0.250)
Cooperation with others				
Cooperation with customers and suppliers		1.348*		1.111*
		(0.212)		(0.277)
Cooperation with competitors		1.543*		0.688*
		(0.156)		(0.247)
Cooperation with research centres		2.926*		2.383*
		(0.175)		(0.249)
Model	-4.762*	-5.010*	-7.441*	-7.493*
	(0.142)	(0.162)	(0.399)	(0.427)
N	6733	6733	6733	6733

Source: author's elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

Table 34: Average marginal effects of the logit model for cooperation with Italian and foreign Universities

	Italian Universities		**Foreign Universities**	
	Model 1	**Model 2**	**Model 1**	**Model 2**
	b/se	b/se	b/se	b/se
Industry variables				
High-tech	0.015***	0.014***	0.007***	0.008**

	(0.009)	(0.008)	(0.004)	(0.004)
KIS	0.046*	0.019**	0.008	0.004
	(0.010)	(0.008)	(0.006)	(0.004)
Average industry investments in innovation activities	0.499*	0.417*	0.197*	0.170*
	(0.176)	(0.158)	(0.068)	(0.062)
Firm variables				
Size (50-249)	0.003	0.001	0.003	0.002
	(0.007)	(0.006)	(0.004)	(0.004)
Size (more than 250)	0.068*	0.050*	0.012*	0.006
	(0.010)	(0.009)	(0.005)	(0.004)
Domestic Group	0.035*	0.024*	0.014*	0.011**
	(0.008)	(0.007)	(0.005)	(0.005)
Foreign Group	0.009	0.000	0.016***	0.015***
	(0.012)	(0.010)	(0.009)	(0.008)
Product and Process Innovations	0.024*	0.012**	0.009*	0.004
	(0.006)	(0.006)	(0.003)	(0.003)
Deviation from R&D industry average	0.012	-0.025	0.008	-0.012
	(0.036)	(0.037)	(0.014)	(0.013)
Innovation Sources				
Intramural R&D	0.058*	0.037*	0.014*	0.009**
	(0.007)	(0.006)	(0.004)	(0.004)
External R&D	0.089*	0.054*	0.012*	0.006***
	(0.009)	(0.008)	(0.004)	(0.003)
Public Funds				
Local public funds	0.056*	0.035*	0.008**	0.004
	(0.009)	(0.008)	(0.004)	(0.003)
National public funds	0.040*	0.016**	0.008***	0.001
	(0.010)	(0.008)	(0.004)	(0.003)
European public funds	0.100*	0.028**	0.058*	0.028*
	(0.016)	(0.012)	(0.010)	(0.006)
Cooperation with others				
Cooperation with customers and suppliers		0.060*		0.014*
		(0.009)		(0.003)
Cooperation with competitors		0.069*		0.009*
		(0.007)		(0.003)
Cooperation with research centres		0.130*		0.030*
		(0.007)		(0.003)
R-squared				
N	6733	6733	6733	6733

Source: author's elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

Table 35: Propensity to cooperate with Italian and foreign Universities (main results)

Explanatory variables	Main results
Industry variables	Belonging to high-tech manufacturing sectors is positively correlated to the cooperation with both Italian and foreign Universities, also taking into account vertical cooperation, horizontal cooperation and cooperation with public research centres. The average marginal effects do not vary significantly in the two cases.
	Belonging to a KIS sector is positively correlated to the probability of being involved in partnerships with Italian Universities, also taking into account cooperation with others (even if the marginal effect significantly lowers in this case), but this result is not statistically significant when taking into account the cooperation with foreign Universities.
	Belonging to sectors with a high level of investments in innovation activities is positively correlated to the engagement in partnerships with both Italian and foreign Universities and this result is statistically significant at 1% level, both taking into account or not variables accounting for cooperation with external partners. The marginal effects are similar in the two cases.
Firm's variables	Size is an important determinant explaining firms' involvement in cooperation partnerships for both Italian and foreign Universities (only in Model 1) also when taking into account the cooperation variables. The marginal effects lowers slightly when taking into account the cooperation variables.
	Belonging to a domestic group is associated to a higher probability to cooperate with both Italian and foreign Universities, also taking into account vertical cooperation, horizontal cooperation and with public research centres. The marginal effects lower slightly when taking into account also the cooperation variables.
	Belonging to a foreign group is associated to a higher probability to be involved in partnerships with foreign Universities but this result is not statistically significant concerning Italian Universities. The marginal effect is substantially the same in Model 1 and Model 2.
	Being highly innovative, that is introducing both product and process innovations, is associated to a higher propensity to cooperate with both Italian and foreign Universities, also when taking into account cooperation variables. In the former case, the marginal effect lowers significantly in the second case.
	No statistically significant results are obtained when measuring the effect of the variable accounting for firm's deviation from the industry average investments in innovation activities.
Innovation Sources	Performing intramural R&D activities is positively associated to the engagement in formal agreements with both Italian and foreign Universities, also taking into account vertical cooperation, horizontal cooperation and cooperation with public research centres. In this second case, the average marginal effect lowers considerably.
	Performing extramural R&D activities is positively associated to the engagement in formal agreements with both Italian and foreign Universities, also taking into account vertical cooperation, horizontal cooperation and cooperation with public research centres. Also in this case the marginal effect lowers considerably, when taking into account the cooperation variables.
Public funds	Receiving regional and national public funds is associated to a higher probability of being engaged in partnerships with both Italian and foreign Universities, but the marginal effects are significantly higher in the former case; moreover, in the second case, they are not statistically significant when taking into account also cooperation with other partners.

	The reception of European public funds is associated to a higher probability to cooperate with both Italian and foreign Universities. However, the marginal effects lower considerably when taking into account also vertical and horizontal cooperation.
Cooperation with other partners	Cooperating with customers and suppliers, competitors and public research centres is positively correlated to engagement in cooperative agreements with both Italian and foreign Universities.

Source: author's elaboration

3.3. Discussion and final remarks

In light of the deep analysis performed in the present Chapter, the initial research questions, RQ1 (RQ1a and RQ1b) and RQ2, reported below may be discussed.

RQ1: In the context of a NIS, characterized by a specific institutional and organizational setting, what is the relationship between the approach to innovation policy, the overall innovation performance and the level of diffusion of PPPs in the system?

- *RQ 1a: In the context of a NIS, characterized by a specific institutional and organizational setting, what is the system's overall innovation and technology performance?*

- *RQ 1b: In the context of a NIS, characterized by a specific institutional and organizational setting, what is firms' propensity to get involved in PPPs and what are the main determinants explaining this trend?*

RQ2: Is a bottom-up/market-driven approach to innovation policies sufficient to stimulate a country's overall innovative performance and level of diffusion of PPPs?

RQ 1a is discussed in section (3.3.1.), RQ 1b in section (3.3.2.) and RQ2 in section (3.3.3.).

3.3.1. The institutional setting, the approach to innovation policy and the overall innovation and technology performance in a NIS

RQ 1a: In the context of a NIS, characterized by a specific institutional and organizational setting, what is the system's overall innovation and technology performance?

First of all, the analysis of the institutional and organizational setting has revealed that the Italian NIS is characterized by some main features: a strong non-homogenous economic and social development with a significant disparity in terms of innovation and technology performance between the Northern and the Southern regions, which exacerbated after the crisis of 2008 (Virgillito and Romano, 2014; Lucchese et al.

2016); the prevalence of micro and SMEs mainly specialized in traditional sectors with low-tech intensity, also due to the special vocation of the country towards high cultural and creative industries (Lazzeretti et al. 2008); the substantial lack or weak presence in most regions of systemic interactions and knowledge flows between public and private players, especially for innovation activities (Virgillito and Romano, 2014; Lucchese et al., 2016).

The analysis of the approach to the innovation and technology policies adopted in Italy and its evolution during the years has shown that, starting from the Eighties, the role of industrial policies has become less and less relevant, also due to the influence of neo-liberal policies diffused throughout all the European countries. Today, the Italian approach to industrial policies have substantially abandoned a 'sectoral' orientation in favour of a more 'horizontal' approach, based on fiscal measures and tax incentives; in addition to the modest resources devoted to R&D-related activities, the measures adopted in this field are highly fragmented (Lucchese et al., 2016).

The strong disparities between the Northern and the Southern regions, the prevalence of micro and SMEs organized in industrial districts and specialized in traditional and low-tech sectors and the lack of a strategic approach to innovation and technology policies are some main reasons that may explain the relatively low innovation and technology performance of the Italian NIS, in comparison to the main European countries.

In fact, the analysis of the Italian positioning in terms of some main Science, Technology and Innovation performance indicators has revealed that the Italian system suffers of a relatively weak performance according to some main indicators: R&D expenditure on GDP, both in the public and in the private sectors, with an underinvestment of the private sector and an overinvestment of the public sector; R&D personnel, turnover from innovation activities, both in the industry and in the service sectors; high-tech export; venture capital; high-tech and not-high-tech patent innovations.

Also the analysis of firms' level of digitalization reveals the country's delay in the adoption of some main ICTs, although some improvements have been made recently, due to the implementation of the Italian industrial plan for 'Industry 4.0' (X Commission Permanente, 2016). In particular, the delay of the Italian firms is related to the relatively low share of ICT in GDP, the adoption of CRM software to analyse the information about clients for marketing purposes and, most significantly, the lack of firms' ICT training courses and low levels of employment of ICT specialists. Relatively better performances concern the adoption of ERP or other software package to share information between different functional areas, confirming the propensity of the Italian firms of being 'better at producing than at selling' (Schivardi, 2016).

In fact, despite the deficiencies mentioned, the Italian NIS is characterized by two important strengths: the presence of a strong manufacturing industry, given the relatively high percentages of the active population employed in manufacturing; the relatively high level of attractiveness of the public research system, confirmed also by the Regional Innovation Monitor Surplus (European Regional Innovation Scoreboard, 2017) and the relatively good worldwide positioning of the country in terms of scientific research rankings.

3.3.2. Firms' propensity to develop PPPs

RQ 1b: In the context of a NIS, characterized by a specific institutional and organizational setting, what is firms' propensity to get involved in PPPs and what are the main determinants explaining this trend?

The analysis of the Italian innovative firms surveyed in the CIS 2010-2012 confirms the relatively low propensity of the Italian firms to get involved in formal PPPs.

First of all, the sample taken into account in the survey is based on a relatively low percentage of firms in the high-tech manufacturing and KIS sectors, which together are equal only to the 19% of the total sample, with the majority being involved in low-tech, less KIS and other sectors. A large majority of firms are SMEs, with only 10% belonging to a class of employees equal or higher than 250 employees. The analysis of the firms' main strategies and goals, in comparison to some main European countries, has revealed the general lack of the firms' long-term vision in business strategies: relatively high percentages of firms consider the reduction of costs and the increase in turnover as main priorities, with a relatively low percentage highly interested in the increase in market share and in profit margins; moreover, a relatively low percentage of firms declared to be highly interested in developing new markets within and outside Europe, building alliances with other firms and institutions, introducing new or significantly improved goods or services and improving the marketing activities. Relatively much attention is devoted to the reduction of costs of purchased materials and of in-house operations. The general lack of the Italian firms' innovativeness and cooperativeness is also hindered by the strong price competition, the lack of internal demand and the high level of bureaucracy, perceived as highly relevant obstacles, compared to the other European countries.

Focusing on the innovative companies, the descriptive analysis has revealed that the firms in the high-tech manufacturing and KIS sectors represent a low percentage of the whole sample and, as expected, they are the most dynamic in terms of innovation activities. The general propensity of firms to cooperate with other firms and institutions is relatively low, in comparison to the other European countries, especially taking into account the percentages of firms having participated to the 7th Framework Programme and of the firms cooperating with Universities for formal R&D agreements, which are mostly concentrated in the high-tech manufacturing and KIS sectors.

In line with the overview of the main empirical studies on the topic, the variables at industry level (the sector and the industry's investments in innovation activities), at firm's level (the size, belonging to a domestic of foreign group of enterprise, having a high level of innovativeness and absorptive capacity) and at local, national and European levels (the reception of public funds) revealed to be significant characteristics of the firms involved in innovation collaborative agreements and the logit estimations have confirmed the statistical significance of the correlations between these variables. Moreover, as highlighted in the work of Segarra-Blasco and Arauzo-Carod (2008), the level of firms' technological intensity has confirmed to be a key factor explaining firms' propensity to innovate and to get involved in PPPs.

In the high-tech manufacturing sector, there is a relatively high concentration of large firms belonging to FMC, thus confirming the relatively low vocation of the Italian NIS towards high-tech activities. They are characterized by relatively high percentages of firms introducing both product and process innovations, performing intramural and external R&D activities and receiving regional and European public funds; they tend to cooperate more with group firms and Universities, both domestic and foreign, given the important influence of FMC. Moreover, firms belonging to foreign groups are characterized by a relatively higher dynamicity with respect to firms belonging to domestic groups in terms of collaborative activities, confirming the relatively lower propensity of the Italian companies to develop collaborative projects with other partners; moreover they are more likely to develop partnerships with foreign Universities, given that cooperation agreements are usually decided at the firms' headquarters and therefore are more likely to be developed with Universities which are geographically closer to the group.

On the contrary, the firms belonging to the KIS sector are characterized by a relatively lower presence of firms belonging to a foreign group, while dominated prevalently by domestic groups; in this sector there are relatively high percentages of firms introducing service innovations, highly investing in R&D activities, which are more likely to cooperate with group firms, competitors, public research centres and Italian Universities. As suggested by Segarra-Blasco and Arauzo-Carod (2008), the participation to European research programs is obviously a strong channel for these firms to be more cooperative and innovative, being able to participate to the international innovation networks. However, as further discussed in the following paragraph, in the substantial lack of a strategic approach to industrial policies, this channel may be insufficient in triggering the country's overall innovation performance.

3.3.3. The lack of a strategic approach to innovation and technology policy: some final remarks

RQ2: Is a bottom-up approach to innovation policies sufficient to stimulate a country's overall innovative performance and level of diffusion of PPPs?

The analysis of the Italian case provides some initial insights into the relationship between a specific institutional and organizational framework, the approach to innovation and technology policies and the level of innovative and technological performance in a NIS.

The case of the Italian country has shown that a prevalently bottom-up/market-driven approach to innovation policies, based on the lack of systemic interactions between the relevant public and private players, fragmented initiatives and prevalently horizontal measures, has not been enough for the system to achieve adequate levels of innovation and technology performance, and collaborative innovation activities on the territory.

The Italian firms have shown a relatively low propensity to innovate and to be involved in formal R&D agreements with other private and public players, which are prevalently driven by factors at industry and firm levels, with a significant influence of FMC, especially in the high-tech manufacturing sector. Public incentives at local, national and European levels are significant drivers of firms' involvement in these PPPs, stimulating vertical and horizontal cooperation, but in itself, are not sufficient to stimulate the country's overall innovation performance.

Despite some recent improvements in the level of adoption of the 'Industry 4.0' KETs, as a result of the Industry 4.0 plan, the lag of the Italian firms in terms of digitalization is still significant, in comparison to the other European countries. The Italian firms' relatively low propensity to invest in R&D activities and to develop synergic and virtuous collaborations with other firms and institutions seriously questions the country's governmental innovation and technology policy approach adopted so far, especially taking into account the complex challenges posed by the rapidly changing technology landscape, analyzed in the first Chapter.

As already mentioned, the current 'fourth industrial revolution' is evolving at an exponential rather than at a linear pace and involving a combination of multiple technologies which are leading to an increasing *multi-disciplinarity* in a variety of contexts, from manufacturing and logistics, to farming and health care, questioning the traditional concept of 'sector' and transforming the entire systems within and throughout countries, companies, industries, cities and the society as a whole (Schwab, 2016). In order for the Italian country not to continue lagging behind, with the risk to exacerbate the distance with the other developed countries, a proper rethinking of effective industrial policies is crucial to avoid critical selection mechanisms, social disparities and political instability (Conference Regione Toscana, 2017).

As the past technological revolutions have shown (Perez, 2010; Perez, 2013; Mazzucato and Perez, 2014), socio-technical shifts cannot occur spontaneously, leaving the forces of the market free to operate according to a 'market failure approach'. The Italian experience is an example in this sense. The definition of a precise socio-political choice (Mazzucato and Perez, 2014) is fundamental in order for the 'Industry 4.0' transition to occur. Given the Italian system's solid manufacturing-based industry and relatively highly attractive public research system, two important strengths of the Italian NIS, a 'mission-oriented' approach to innovation policy, combining both top-down and bottom-up measures, may provide interesting inspirational principles of action, orienting public investments in precise strategic lines of action, triggering the necessary cross-disciplinary, cross-sector and cross-actor synergies across the economy and raising the overall innovation potential of the system (European Commission, 2018). This approach to policy making could be able to catalyze the economic and social resources in the country, guiding it strategically towards a sustainable development trajectory, avoiding technological lock-ins and preventing it from the loss of competitive advantge (Lucchese et al. 2016).

As shown in the previous Chapter, some sources of inspiration for the definition of effective industrial policies are provided by the industrial plans of the major industrial powers, like the U.S., financing heavily the network of manufacturing institutes specialized in highly advanced technological domains, which combine a clear strategic approach of the public action with multiple bottom-up solutions, thus enhancing the country's economic and social resources; or as the German Platforme Industrie 4.0, which brings together businesses, the academy and the government in order to exploit the virtuous potentialities of the 'Industrie 4.0' revolution, through a network of local and global strategic players.

The progressive integration between the ‘physical’ and the ‘virtual’ dimensions, which is widening exponentially the global connective space, questions also the meaning of the territorial and geographical dimensions of NISs, implying the need for the traditional categories used in innovation studies to adapt in order to deal with the present technological scenario; the radical transformation that the ‘Industry 4.0’ KETs are bringing throughout the economy and every aspect of human life requires adequate lenses of analysis able to properly explain the new dynamics of innovation and a new rethinking of the role of the public actor in driving these processes.

The following Chapter presents the case of an Italian RIS, which may enrich our understanding of how can institutions and organizations manage the multiple challenges lying behind this socio-technical transition, showing the crucial importance of the public institutions in influencing a system’s innovation performance.

4. Chapter Four: The socio-technical transition towards 'Industry 4.0' in a Regional Innovation System, the case of the Autonomous Province of Trento

The present Chapter is divided in the following sections. In order to provide the empirical framework for the case study analysis, the first section (4.1) briefly examines the literature on RISs, describing the structural elements and the different regional development paths for different RIS types. The second section (4.2) contains the full in-depth description of the case of Trento, discussing the main performances and trends, the institutional framework and the results of the interviews and presenting some significant business case studies. The third section (4.3) discusses the case of Trento in the light of the research questions specified in section 2.3.2.

4.1. RISs: the empirical framework

As discussed in Chapter One, one of the most relevant contributions of the systems' of innovation approach has been the concept of innovation as an evolutionary, non-linear and interactive process, based on the cooperation between public and private players, such as firms, Universities, public research institutes, technology centres, educational institutes, financing institutions, industry associations and government agencies. Whereas early research was focused on NISs (Lundvall, 1992; Nelson 1993), the significant differences between regions in terms of innovation performances stimulated a growing interest of academics and scholars in the regional dimension of innovation systems. Trippl (2006) highlights three main reasons for which regions are a particularly useful unit of analysis: they show important differences in the patterns of industrial specialization and innovation activities; they facilitate the diffusion of knowledge spillovers, which are often geographically confined and play an important role in innovation processes; they support tacit knowledge exchange processes, thanks to spatial proximity; they present strong differences in their policy making mechanisms and institutional background. Doloreux and Dionne (2008) define a RIS as "a concentration of interacting private and public interests, formal institutions, and other organizations that function according to organizational and institutional arrangements and relationships conducive to the generation, use and dissemination of knowledge" (Doloreux and Dionne, 2008, p.260).

In order to define the analytical tools for the analysis of the case of Trento, the present paragraph is dedicated at going more in-depth into the structure of the RIS, according to the works of Autio (1998) and Tödtling and Trippl (2005).

4.1.1. Structure of the RIS and RIS types

Drawing on Autio (1998), Tödtling and Trippl (2005) have elaborated a schematic summary table on the structure of the RIS, which identifies some basic dimensions: knowledge generation and diffusion, knowledge exploitation, regional policy subsystems, local interaction, socio-institutional factors. Figure 15 here below shows the main structural elements and linkages in a RIS.

Knowledge generation and diffusion subsystem (knowledge infrastructure)

According to Tödtling and Trippl (2005), the knowledge generation and diffusion subsystem of a RIS is based on all the organizations involved in the production and dissemination of knowledge. It basically consists of "(...) public research institutions, technology mediating organisations (technology licensing offices, innovation centres, etc.) as well as educational institutions (Universities, polytechnics, vocational training institutions, etc.) and workforce mediating organisations[149]" (Tödtling and Trippl, 2005, p. 1205).

In the literature, the interaction between the different players of the knowledge generation and diffusion subsystem has been often represented by the Triple Helix model (Leydesdorff, 2000; Etzkowitz, and Leydesdorff, 2000). A recent application of the Triple Helix model is contained in the work of Fernández-Esquinas et al. (2016) who analyzed the role of interface organizations in the dynamics of knowledge transfer in a RIS. The authors identify three main micro-components of the Triple Helix model: Technology Transfer Offices (TTOs), science parks and innovation agencies. Since 1980s, the literature on TTOs (Bozeman, 2000) has focused the attention on the growing "entrepreneurial approach" of Universities, with the different activities they need to manage, like intellectual property rights, networking activities with the industry and the formation of academic spin-offs. The work of Bruneel et al. (2010) on University-industry linkages suggest inter-organizational trust as one of the most important factors able to reduce the barriers between Universities and industry. "Building trust between academics and industrial practitioners requires long-term investment in interactions, based on mutual understanding about different incentive systems and goals. It also necessitates a focus on face-to-face contacts between industry and academia, initiated through personal referrals and sustained by repeated interactions, involving a wide range of interaction channels and overlapping personal and professional relationships" (Bruneel et al., 2010, p. 867).

A second group of studies investigates the role of science and technology parks as locations in which innovative firms and knowledge providers concentrate; as underlined in Fernández-Esquinas et al. (2016) science and technology parks are usually developed to attract high-tech companies, to stimulate clustering mechanisms related to the research expertise of the local Universities and research centres and to attract investors from outside. Whereas many empirical studies underline a positive impact of science parks on the propensity to innovate and to form R&D collaborations, a low absorptive capacity, low levels of R&D investments and low 'cultural background' of the member organizations (Bigliardi et al., 2006) may represent important obstacles for the innovative capacity of these firms.

Finally, a third group of studies focuses on the role of innovation agencies specialized in providing entrepreneurial and funding support. "These organizations may operate as institutional bridges among all the players involved in the regional innovation system (...). It is assumed that public policies implemented by

[149] Doloreux (2002) has selected three main categories of the knowledge generation and diffusion subsystem. The first category includes essentially science parks, technology parks and incubators and all the structures aimed at stimulating and promoting innovation and technology diffusion; a second is formed by agencies in charge of transfer activities and technical advisory for knowledge-based companies; the third by institutions and infrastructures directly responsible of knowledge generation, like Universities, national laboratories, research centres and R&D units.

innovation agencies are a rich instrument to enhance regional partnerships and social capital, making transformation and growth possible" (Fernández-Esquinas et al., 2016, p. 427).

Regardless of the specific 'micro-component' of the Triple Helix model involved, the relationships between industry and academia may suffer of a mismatch in priorities, purposes and organizational approaches. Bozeman (2000), on the basis of a study of U.S. R&D laboratories, points out that University laboratories are more focused on basic research while governmental laboratories more on applied research with the latter being more flexible and able to perform interdisciplinary research with respect to the former, more rigid in their organizational structure. Given that applied research made by the industry is based on yesterday's basic research, it is necessary to maintain a correct balance between basic and applied research in order to avoid the risk for research centres to lag behind in the future.

The knowledge application and exploitation subsystem

The knowledge application and exploitation subsystem consists of the 'entrepreneurial' dimension of a RIS, which essentially is based on "the industrial clusters located in the region" (Trippl, 2006, p. 4). Industrial clusters are defined in Porter (1998) as "geographical concentrations of interconnected companies, specialized suppliers, service providers, firms in related industries, associated institutions (for example Universities, standard agencies, and trade associations) in particular fields that compete but also cooperate" (Porter, 1998, p.197). Porter (1998, p. 181) states: "A cluster allows each member to benefit as if it had greater scale or as if it had joined with others without sacrificing flexibility". Geographical proximity facilitates interaction and communication between the players of the cluster, where R&D activities, patenting and product innovations are therefore stimulated (Tödtling and Trippl, 2005).

The work of Tödtling and Kaufmann (1999) underlines how an important factor explaining the propensity of firms to interact with other players and to innovate is the size of the firms involved; small firms, with less than 50 employees, interact mainly with customers inside the region[150]; medium sized companies, with employees between 50 and 200, have more partners in the innovation process, including also support organizations like TTOs, training institutions and public institutes. Finally, large firms, with a number of employees higher than 200, usually have a high number of partners, mainly Universities, customers and suppliers at European and global scale.

The regional policy subsystem

This subsystem was not included originally in the work of Autio (1998) and has been added by Tödtling and Trippl (2005); according to the authors, it consists of political government departments, regional development agencies and other political players involved in the elaboration and implementation of innovation policies and cluster strategies.

During the years, the regional innovation policy has shifted from a 'top-down' science-based approach, based on standardized and place-neutral policies to a 'bottom-up' and placed-based approach

[150] According to the authors, this result is surprising, as small firms should have a higher need with respect to medium and large firms to complement the lack of internal resources.

(Barca, 2009), where priority areas of policy intervention is the result of an "entrepreneurial discovery process" (Foray et al., 2009). Amin (1999) cited in Hassink (2002, p.155) states that regional innovation policies have shifted from "firm-centred, incentive-based, state-driven and standardized regional economic development (...) to bottom-up, region-specific, longer-term and plural actor policies". Smart Specialization Strategies, the new innovation-policy paradigm of the European Union (European Commission, 2012) represents the translation in practical terms of this shift. This policy concept "is about placing greater emphasis on innovation and having an innovation-driven development strategy in place that focuses on each region's strength and competitive advantage. It is about specialising in a smart way, i.e. based on evidence and strategic intelligence about a region's assets and the capability to learn what specialisations can be developed in relation to those of other regions" (European Union, 2011, p. 7). Crucial for the implementation of Smart Specialization Strategies is the need to avoid the "one-size-fits all" strategies (Tödtling and Trippl, 2005) and the creation of a knowledge generation and diffusion subsytem.

Another significant aspect of the regional policy subsystem is the type of regional governance; the 'policy capability' to support regional economic development is based on an adequate level of financial autonomy (Tödtling and Trippl, 2005; Cooke et al. 1997; Trippl, 2006). Cooke et al. (1997) distinguish between three main types of spending capacity: regions with decentralized spending, characterized by a low level of autonomy in orienting the innovation system; regions with financial autonomy, which can design their own innovation policies, balancing taxation with public spending; regions with taxation authority, carrying out innovation policies through public spending and the fiscal system.

Local interactions

In order for a system to perform successfully, the existence of the regional subsystems identified above is not sufficient. What makes the difference in terms of innovation performance of the whole region is the level of interaction between the subsystems and the overall system's absorptive capacity (Fritsch, 2002). As underlined in Trippl et al. (2015a), drawing on Asheim and Coenen (2006), the level of the interaction between the elements of the subsystems depends on the type of knowledge base adopted in the cluster. According to Asheim and Coenen (2006), the innovation processes depend on the type of knowledge base firms and organizations adopt. Three main types of knowledge bases are identified: analytical[151] synthetic[152] and symbolic[153]. The literature distinguishes between different kinds of RISs on the basis of the type of knowledge base supported (Trippl et al., 2015a): in the narrowly defined RIS, the knowledge exploration

[151] Analytical knowledge base mainly prevails in research-intensive industries like for example biotechnology and nanotechnology for which innovation is strongly influenced by scientific development. This type of knowledge is often linked to radical new products and processes, needing both basic and applied research; regions characterized by this type of knowledge are also characterised by frequent linkages between firms and public institutions; analytical industries are frequently characterized by a 'science-technology-innovation' (STI) mode.

[152] A synthetic knowledge base prevails in mature industries, like industrial machineries or food processing; more linked to incremental innovations, this type of knowledge relies more than the analytical one on a 'doing-using-interacting' (DUI) mode of innovation. In this case, the interactions are mainly with customers and suppliers and the links between university and industry are important but are related more to applied research than basic research.

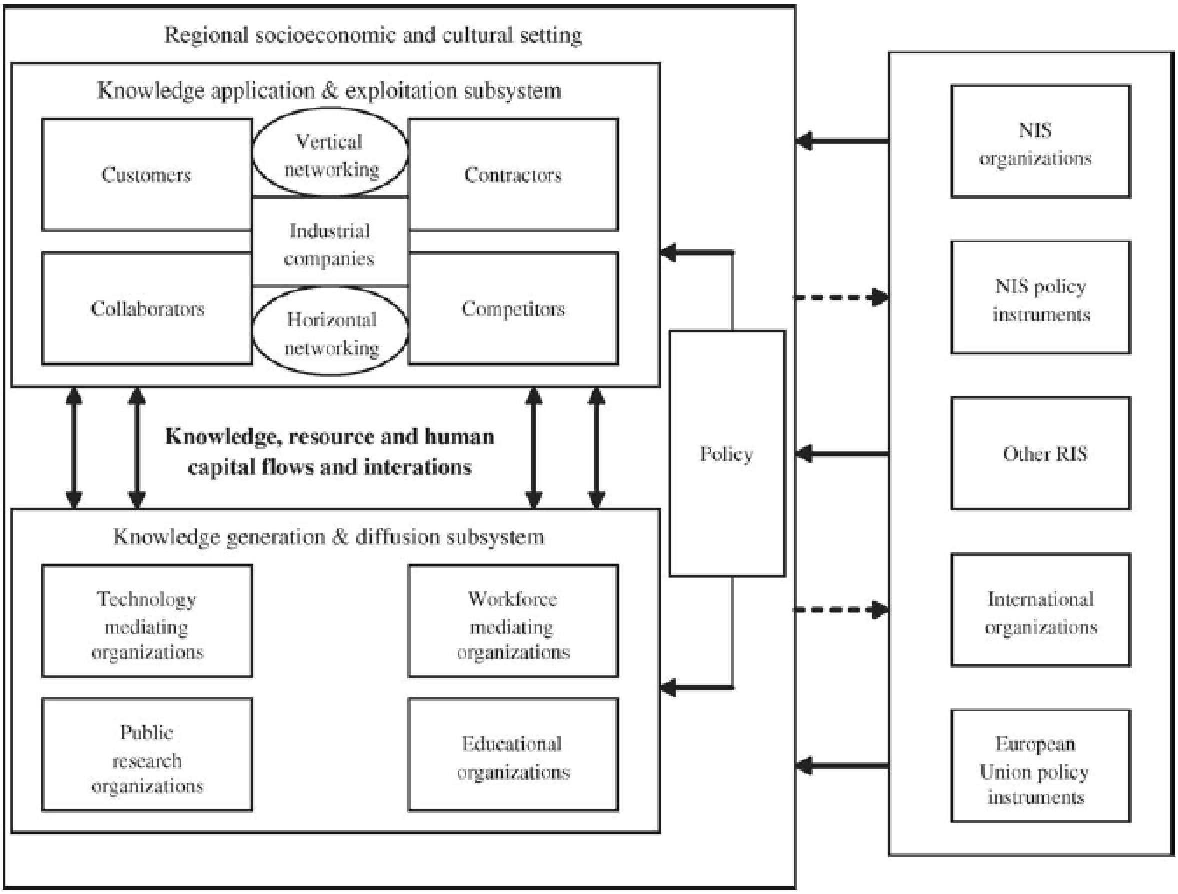
[153] The symbolic knowledge base may be found prevalently in creative and cultural industries, linked to the creation of intangible values, such as aesthetic values, it is highly context specific, with innovation occurring prevalently in project teams.

subsystem and the knowledge exploitation system interact one with each other in support of the STI mode of innovation; in the broadly defined RIS the two subsystems interact in support also of the DUI mode of innovation comprehending a broader set of institutions.

Socio-institutional factors

Socio-institutional factors include both the 'hard' or formal dimension of the institutions, like laws, regulations and so on and the 'soft' or informal dimension of institutions, such as values, practices, and routines. The institutional dimension of the RIS shapes the players and their interactions in the system. Key elements of the socio-institutional dimension of the RIS are for example cultural traditions, values and routines, patterns of behaviour and the attitude towards innovation and technology. While socio-economic elements like the culture of cooperation, trust, the sense of belonging, informal interaction relationships favour the overall performance of the RIS, individualism and the lack of a cooperative approach between the players of the innovation system constitute important obstacles to local development (Cooke, 1998).

Figure 15: Structural elements of a RIS



Source: Tödtling and Trippl (2005) elaboration on the basis of Autio (1998)

Regional barriers

Once defined the main elements of the structure of the RIS, different types of RISs can be identified, according to the different system deficiencies, or system failures, that may be responsible for a weak innovation performance. Tödtling and Trippl (2005) have applied the system failure approach to the regional level to analyse various deficiencies of RISs. The authors distinguish between three forms of system deficiencies: organisational thinness, negative lock-in and fragmentation (Table 36).

Organizational thinness refers to the lack or weak development of essential elements of a RIS linked to the firms or organizations of a RIS; for example, a RIS characterized by the absence or a weak presence of a critical mass of innovative firms, other key organizations and institutions and low levels of clustering. It is the case of peripheral areas (Doloreux and Dionne, 2008) characterized by a an insufficient level of R&D and innovation, due to the prevalence of SMEs in traditional sectors, weak presence of assets supporting new industries, weak capacity to absorb knowledge generated outside the region, due to a thin structure of supporting organizations.

Locked-in RISs, characterized by over-embeddedness and over-specialization in mature sectors and out-dated technologies; it is often the case of locked-in RISs prevailing in old industrialized areas with a limited capability to generate radical innovations; in this case different forms of negative lock-in may occur: functional, cognitive and political ones, which represent important obstacles to development paths.

Fragmented RISs are characterized by the lack or weak interactions between the main players of the system, implying insufficient levels of collective learning and systemic innovation activities which can be typically found in metropolitan areas, characterized by the presence of a critical mass of firms and research organizations, which, however, have a weak propensity to collaborate with each others.

As a result of the combination of different types of inefficiencies (Trippl et al. 2015a), less developed RISs may be categorized in four main types, distinguishing between organizational/institutional thickness/thinness (Table 37).

Institutionally thick but organizationally thin RISs are characterized by a strong presence of both formal and informal institutions, which are, however, associated to the lack of organizations, such as research institutions which may be an important source of generation of radical forms of innovation. Italian industrial districts are indicated as examples of this category, due to the presence of thick institutions, a strong culture of cooperation and the lack of research organizations or science-based firms.

Organizationally thick but institutionally thin RISs are characterized by the presence of a critical mass of firms and research, educational and other supporting organizations, but with a lack of solid institutions supporting cooperation culture between the different players of the system. It is the case of large cities in Southern and Eastern Europe.

Institutionally and organizationally thin RISs are characterized by a weak presence of innovation-relevant organizations, the lack of solid institutions, resulting in a low overall innovative performance. It is the case of the peripheral regions located in the South and East of Europe.

Institutionally thick and organizationally thick RISs are based on both solid formal and informal institutions and organizations; it is the case of the metropolitan/city regions in Northern and Western Regions.

Table 36: Types of regions according to the system failures/deficiencies

System failure / deficiencies	Type of Regions
Organisational thinness: crucial elements of a RIS are missing: low levels of clustering & weak endowment with key organisations	Peripheral regions
Negative lock-in: over-embeddedness & overspecialization	Old industrial areas
Fragmentation: lack of interaction between RIS elements	Metropolitan regions

Source: Trippl et al. (2015a)

Table 37: Organizational and institutional thickness/thinness of a RIS

	Organizational Thickness	**Organizational Thinness**
Institutional Thickness	Metropolitan/city regions in Northern and Western Regions	Industrial districts in the Third Italy, Nordic peripheral regions
Institutional Thinness	Larger cities in Southern and Eastern Europe; OIA in Western Europe	Southern and Eastern peripheral regions

Source: Trippl et al. (2015a)

Recent works on RISs have focused the attention on the relationship between RIS types and industrial path development patterns (Table 38). Drawing on Asheim et al. (2013) and Tödtling and Trippl (2013), three main forms of regional industrial path development are identified (Trippl et al., 2015a): path extension generally develops along existing technological paths, through incremental innovations in existing firms and industries; the result may be the loss of regional competitive advantage in the long run; path renewal occurs when existing firms and industries develop in different but related activities and sectors; Boschma and Frenken (2011) indicate this process as "regional branching" and "related diversification"; new path creation results from the development of firms in completely new sectors and from the introduction of radical innovations. A strategic policy action with supportive institutional structures is often an important key for new path creation processes.

Isaksen and Trippl (2014) analyze the relationship between different RIS types and various forms of regional industrial path development, identifying three types of RISs: organizationally thick and diversified systems; organizationally thick and specialized systems; organizationally thin systems. These RISs types generate different path development processes (Table 38).

Organizationally thick and diversified RISs stimulate path renewal and path creation processes thanks to virtuous mechanisms associated to the presence of knowledge-based organizations and a broad spectrum of different but related industries and knowledge bases; organisationally thick and specialized RISs favour path extension processes, based more on incremental rather than radical innovation processes[154]. Organizationally thin RIS usually follow path exhaustion processes, due to the incapability to trigger renovation mechanisms.

[154] In this case there is a possible risk of path exhaustion if positive lock-in switches into negative lock-in.

As underlined in Trippl et al (2015b), non-local knowledge flows play a significant role in regional development paths[155].

Organizationally thick and diversified RISs have a low necessity to be supported by extra-local knowledge flows, since they are well-endowed with local sources of knowledge; however, they are characterized by a high level of attractiveness of non-local knowledge, due to their highly dynamic environment; on the contrary, both organizationally thick and specialized RISs and organizationally thin RISs have a high need to attract non-local knowledge flows, since they are not well endowed with local knowledge sources, which they need to integrate with exogenous ones; both these RIS types may switch to path renewal and path creation processes, if they improve their capacity to attract non local knowledge flows.

Table 38: RISs types and regional industrial path development patterns

RIS types	**Main characteristics**	**Typical development patterns**	**The role of non-local knowledge flows**
Organizationally thick and diversified RIS	Wide range of heterogeneous (but related) industries and knowledge bases	Path renewal and new path creation	Low need for extra-local knowledge but high capacity to attract non-local knowledge
Organizationally thick and specialized RIS	Narrow industrial base, specialized knowledge and support structure	Path renewal Path extension (positive lock-in) Path exhaustion (negative lock-in)	High need for extra-local knowledge but low attraction capacity
Organizationally thin RIS	Weakly developed clusters and poor knowledge support structure	Path Exhaustion	High need for extra-local knowledge but low attraction capacity

Source: author's elaboration drawing on Trippl et al. (2015a) and Trippl et al. (2015b)

In light of the empirical framework overviewed, the following paragraph provides a detailed analysis of the case of Trento, with a summary of the main performances and trends, the institutional framework and the results of the field interviews.

[155] There are two main types of non-local knowledge flows identified: at local level, like the ones deriving from new players, prevalently research organizations, skilled researchers and companies; at extra-local level, like global R&D collaborations and the participation to international trade fairs.

4.2. The case of the Autonomous Province of Trento

4.2.1. Overview of the main performances and trends

Socio-economic and R&D indicators

Trento is a special status Province located in Northeast Italy, in the central Alps; with a surface of 6.207 Km² and about 70% or more of the territory over 1.000 meter altitude, it is one of the less densely populated regions in Italy and in Europe, with a population equal to 538.223 inhabitants in 2016, about 1% of the national population. Table 39 summarizes Trento's main socio-economic indicators compared to Italy and to the European Union. As the table shows, Trento presents relatively good indicators of social-economic wellbeing with respect to Italy and Europe. The labour market shows positive trends: in 2015, the activity rate was 71%, higher than the national rate (64%) and slightly lower than the European rate (73.4%); the employment rate was 66.1% equal to the European rate and higher than the Italian rate (56.3%); the unemployment rate was equal to 6.8%, lower both than the Italian rate (11.9%) and the European rate (9.8%). In 2014, the GDP per capita (at current prices) was of Euro 34.196, higher than Italy (Euro 26.549) and Europe (Euro 31.860).

Table 39: Main socio-economic indicators in Trento, Italy and EU-15

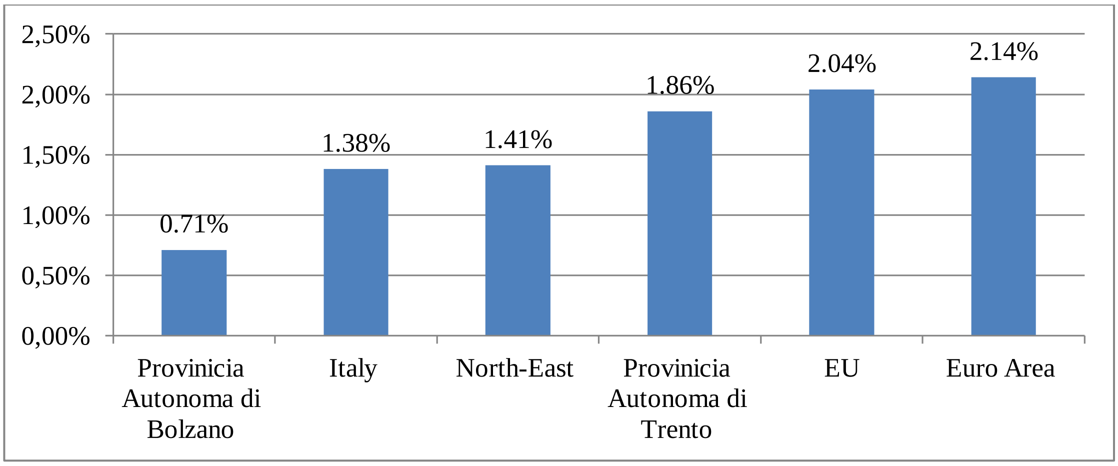
Indicators	Year	PAT	Italy	EU-15
Population	2016	538.223	.	
Surface	.	6.207 Km².	.	
Activity rate	2015	71%	64%	73.4%
Employment rate	2015	66.1%	56.3%	66.1%
Unemployment rate	2015	6.8%	11.9%	9.8%
GDP current prices (million)	2014	€ 18.357,00	€ 1.613.859,00	€ 12.834.489,00
GDP per capita current prices	2014	€ 34.196,00	€ 26.549,00	€ 31.860,00

Source: author's elaboration on Istituto di Statistica della Provincia di Trento (ISPAT) data.

According to a report of the national statistical institute, ISTAT, concerning fair and sustainable wellbeing (BES, 2016), Trento is at the first position among the Italian regions, according to different socio-economic indexes: subjective wellbeing, environmental conditions, educational level, the level of trust in the institutions, the preservation of the cultural heritage and the use of renewable energy resources. This is confirmed by data on life expectancy in good health (PAT, 2016) which in Trento is equal to 60.2 years for women (against 55.2 years in Italy) and 62.1 years for men (against the 57.8 years in Italy). The socio-well being indexes are one of the main criteria entering in the ICityRate ranking of smart cities developed by Italian FORUMPA, the institute that evaluate Italian smart cities, for which Trento was awarded in 2016 with the eighth place.

Despite the relatively low density of the population and the relatively disadvantageous geographic and orographic conditions, Trento performs well in terms of some main indicators accounting for innovation activities, both with respect to the Italian and to the European averages. Figure 16 shows the level of R&D expenditure on GDP at current prices in 2014 in Trento, Provincia Autonoma di Bolzano, Northeast Italy[156], the European Union average (28 countries) and the Euro area (19 countries). In 2014, the level of total R&D expenditure on GDP in Trento was of 1.86%, higher than Provincia Autonoma di Bolzano (0.71%), the Italian average (1.38%), Northeast Italy (1.41%) and close to EU (2.04%) and the Euro Area (2.14%).

Figure 16: R&D expenditure on GDP at current prices in 2014 in Trento, Bolzano, Italy, North-East and EU

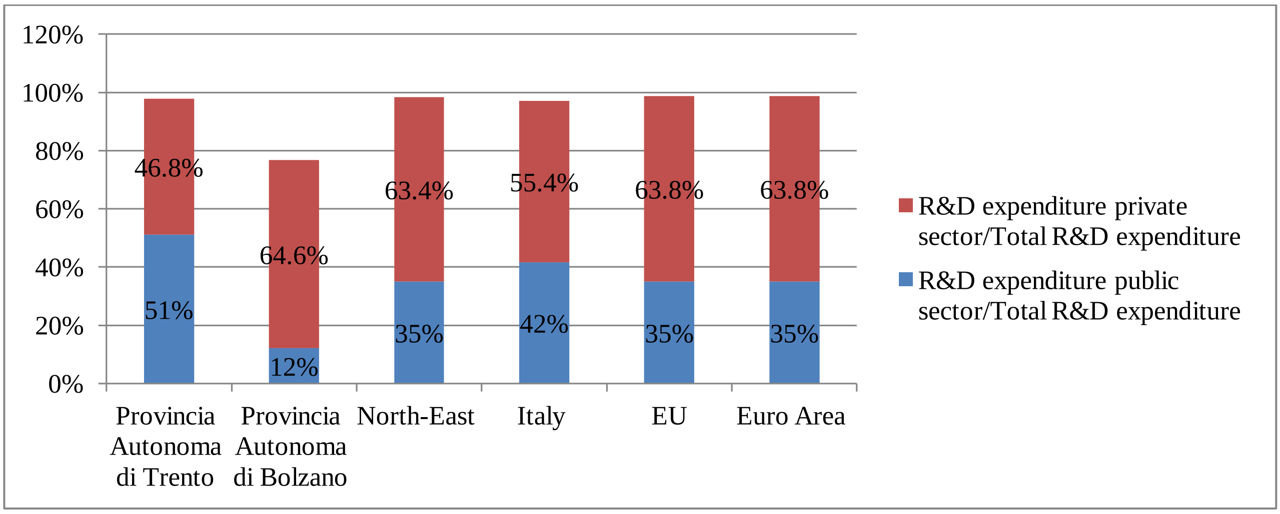


Source: author's elaboration on ISPAT data.

Taking a look at the shares of R&D expenditure of the private and public sectors (Figure 17), Trento shows a rather equal distribution between the two, with the public sector investing slightly more than the private sector (51% vs. 46.8%); on the contrary, the European Union, Northeast Italy and Provincia Autonoma di Bolzano show a distribution of the R&D expenditure in favour of the private sector. The Italian country as a whole has a higher percentage of R&D expenditure in the private sector (55.4%), but the share in the public sector is still quite high (42%).

156 North East includes Emilia Romagna, Friuli-Venezia Giulia, Trentino-Alto Adige and Veneto, in accordance to the ISTAT and the EUROSTAT definitions.

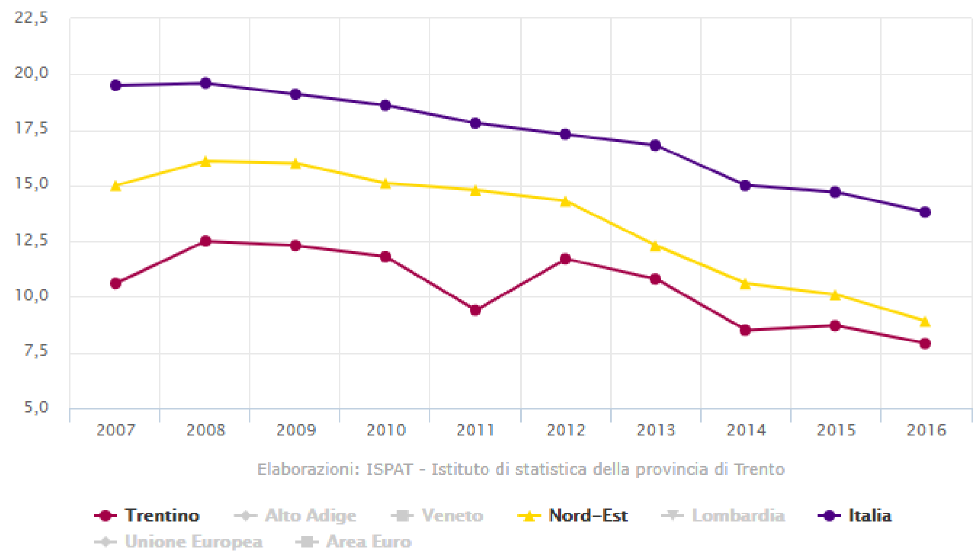
Figure 17: R&D expenditure on GDP at current prices by sector in 2014 in Trento, Bolzano, Italy, North-East and EU



Source: author's elaboration on ISPAT data

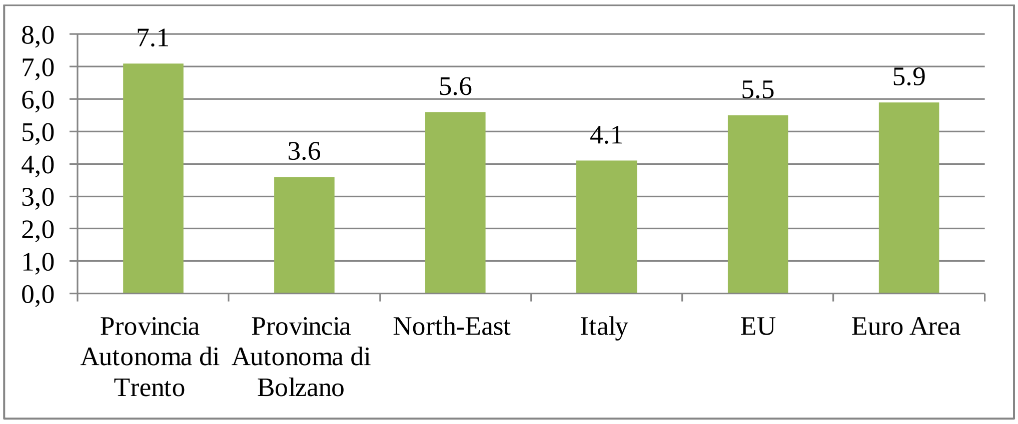
The level of education in Trento is relatively high, according to some main indicators. Figure 18 provides the school dropout rate for population between 18-24 years old with Trento showing better performances than the Northeast of Italy and Italy. Similarly, Figure 19 presents the total number of R&D employees per 1000 inhabitant with Trento having the relatively highest concentration (7.1) followed by the Euro area (5.9), the Northeast Italy (5.6), the EU (5.5), Italy (4.1) and Provincia Autonoma di Bolzano (3.6).

Figure 18: School dropout rate for population between 18-24 years old in Trento, North East and Italy



Source: ISPAT

Figure 19: Total R&D employees per 1000 inhabitants in Trento, Bolzano, North-East, Italy and EU

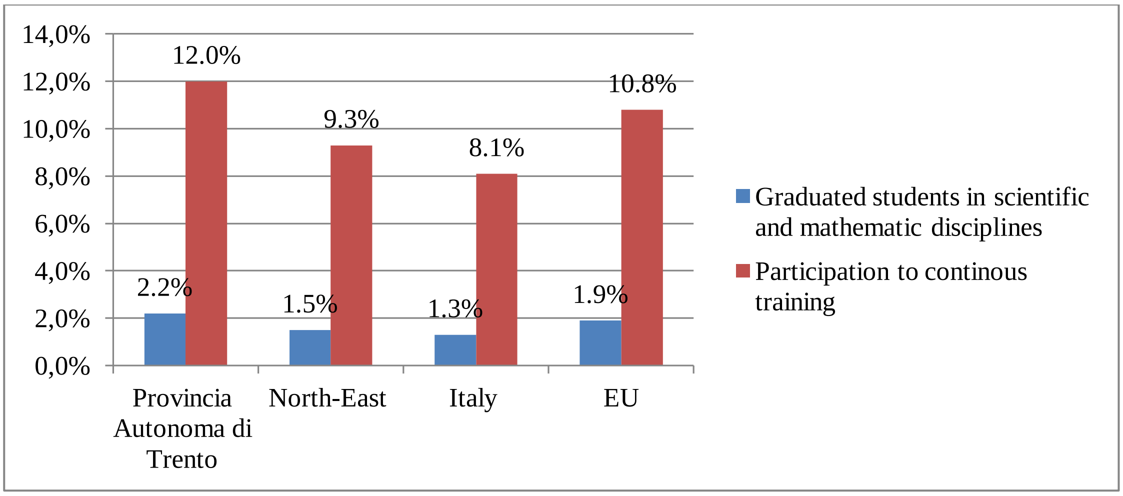


Source: author's elaboration on ISPAT data.

Moreover, Figure 20 shows the share of graduated students in mathematical, scientific and technological disciplines on the total population between 20-29 years and we can see that Trento has the relatively highest percentage (2.2%), followed by the EU (1.9%), Northeast Italy (1.5%) and Italy (1.3%). Also data accounting for the participation to continuous training[157] shows relatively good performances: 12% in Trento followed by the 10.8% in the EU, the 9.3% in the Northeast of Italy and 8.1% in Italy.

[157] This indicator accounts for people between 25-64 years participating to continuous education and training activities.

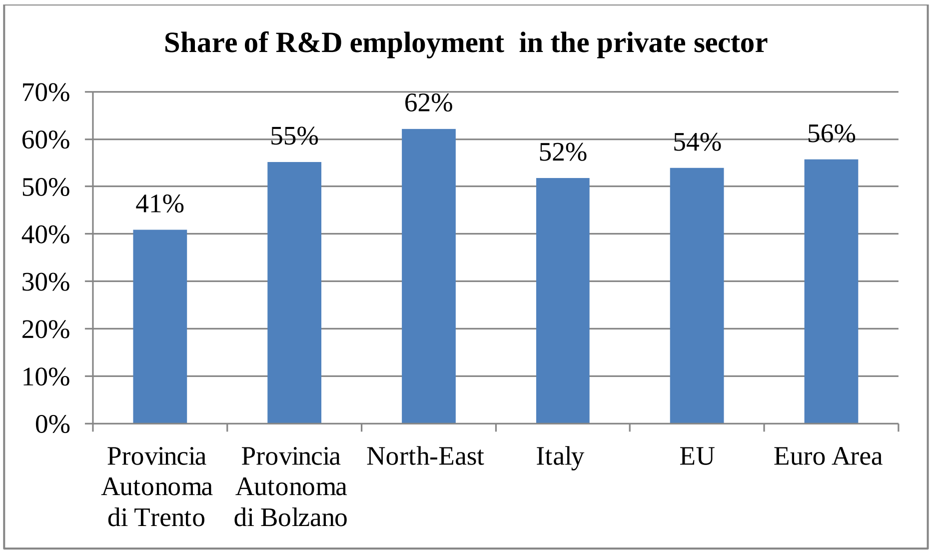
Figure 20: Graduated students in scientific and mathematical disciplines and participation to continuous training in Trento, North East, Italy and EU



Source: author's elaboration on ISPAT data.

However, data on the share of R&D employment in the private sector (Figure 21) confirm the relatively weaker performances of the private sector with respect to the public sector. As can be seen, Trento has the relatively lowest percentage of R&D employment (41%), followed by Italy (52%), EU (54%), Provincia Autonoma di Bolzano (55%), Euro Area (56%) and the Northeast of Italy (62%).

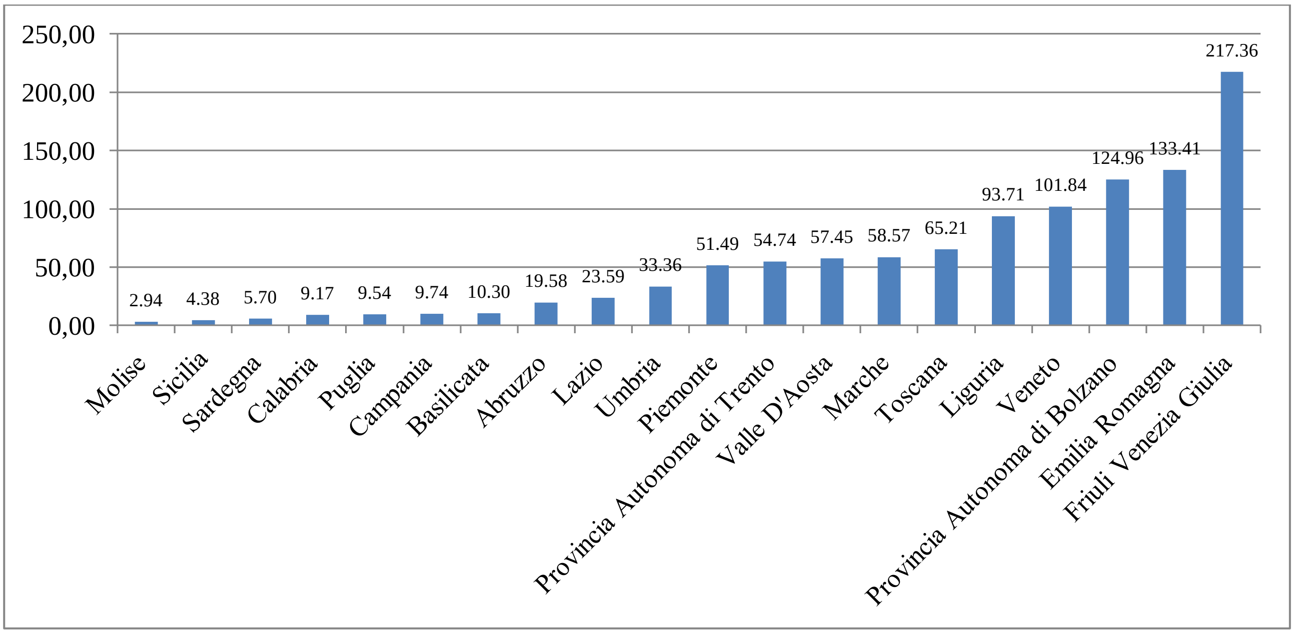
Figure 21: Share of R&D employment in the private sector in Trento, Bolzano, North-East, Italy and EU



Source: author's elaboration on ISPAT data.

A further proof of this trend is provided by data on patent applications to the European Patent Office (EPO) (Figure 22). Due to its particular business structure, based on the prevalence of micro and SMEs, Trento counts a number of patent applications each million of inhabitants between 2011 and 2012 which is lower than most Northern Italian regions.

Figure 22: Patent applications to the European patent office per million of inhabitants by Italian region



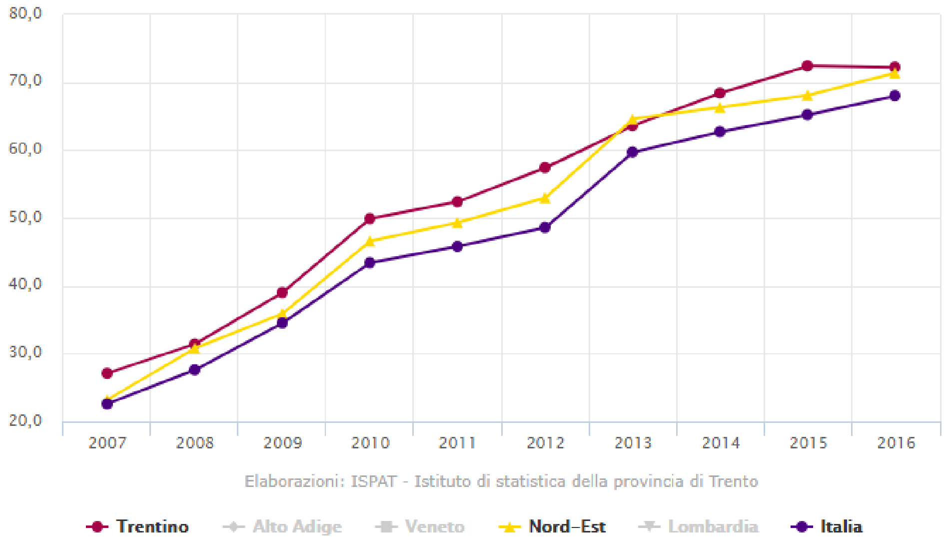
Source: author's elaboration on ISPAT data.

Despite the prevalence of micro companies and SMEs, according to PAT (2016), Trento is the fourth Italian region in terms of number of innovative start-up developed since 2012 (53), following Milan (129), Rome (101) and Turin (86). These are divided in the following areas of specialization: 67% in the service sector, mainly in ICT and research and development; 27% in the industrial sector, mainly in mechatronics. Moreover, according to a report realized by CERVED (2016), Trento is the most innovative Province not only in terms of innovative start-ups but also in terms of innovative SMEs[158]. "The case of Trento and Trieste are meaningful examples of Provinces in which the presence of innovative start-ups and SMEs is very much higher than the Italian average in each of the eight clusters identified" (own translation, CERVED, 2016, p. 148).

Finally, taking a look at the indictors accounting for families' and companies' access to ICT, Trento shows relatively good performances, with respect to Northeast of Italy and Italy as a whole. Figures 23-24 here below show the percentage of families having access to the Internet with broadband connection on total families and the access to a broadband or mobile connection for firms with 10 or more employees.

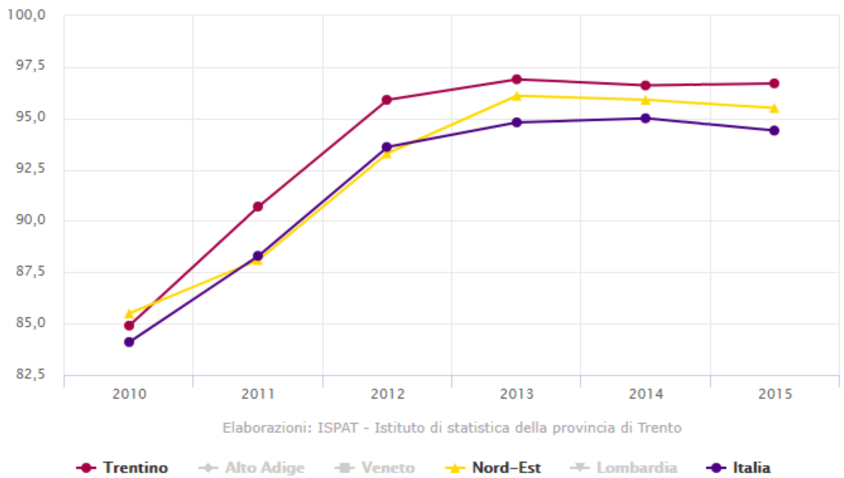
[158] The authors of this report performed a semantic web analysis to identify the websites of the innovative startups and SMEs identifying eight main innovative clusters: mobile and smart phone, software and internet of things, eco-sustainability, biotechnologies, big data and internet app, 3D modelling, research and development and engineering. The report confirms that Trento is in the first place among the Italian regions in the furniture cluster and eco sustainability, second place in the cluster of biotechnologies, software and Internet of Things, 3D modelling, research and development, fourth place in engineering, and seventh place in big data and internet app.

Figure 23: Percentage of families having access to the Internet with broadband connection on total families in Trento, North-East and Italy



Source: author's elaboration on ISPAT data.

Figure 24: Percentage of firms with 10 or more employees having access to a broadband or mobile connection to the Internet in Trento, North-East and Italy



Source: author's elaboration on ISPAT data.

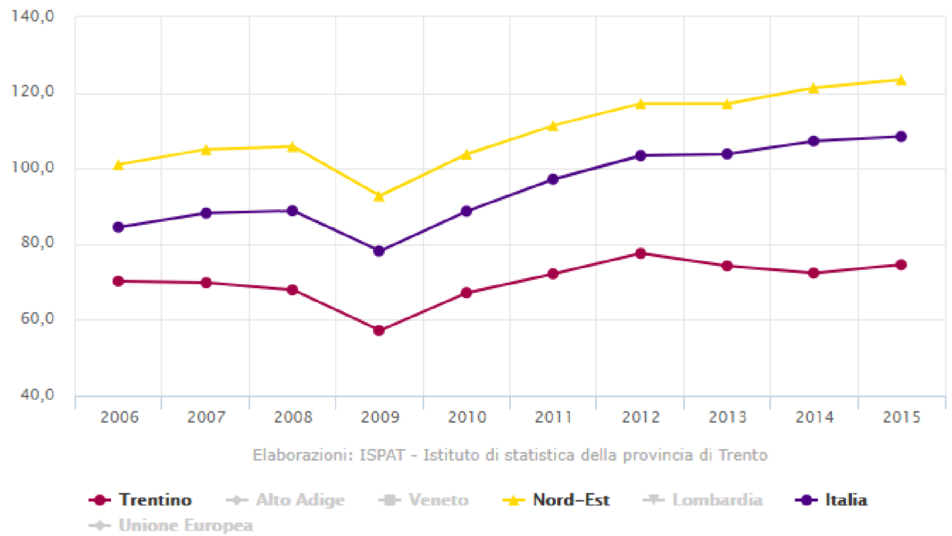
The following paragraph gets more in depth into Trento's business structure.

The business structure

The business structure in Trento (Camera di Commercio di Trento, 2014) is based on the prevalence of micro and SMEs, in line with the overall Italian industrial system, due to the relatively small portion of territory which can be dedicated to industrial activities: the total number of micro and small enterprises (with a number of employees lower than 50) is equal to the 73% of the local units, the total number of medium enterprises (with a number of employees between 51 and 200), is equal to the 23.5% and the total number enterprises with over 200 employees is equal to the 3.5%. In terms of production units, the manufacturing industry accounts for the 61.2% of the total industrial compartment[159]. The share of the manufacturing industry in terms of occupation level is of the 69.7%. However, the industrial compartment contributed in 2014 to the total value added[160] only for the 23.5%, much lower level than the service sector, accounting for the 73.1%[161].

Firms' level of internationalization is relatively low in comparison to Northeast Italy and Italy. Figure 25 and Figure 26 show, respectively, firms' propensity to export and the percentage of exports in the manufacturing sector on GDP at current prices: Trento performs in both cases worse than Northeast of Italy and Italy.

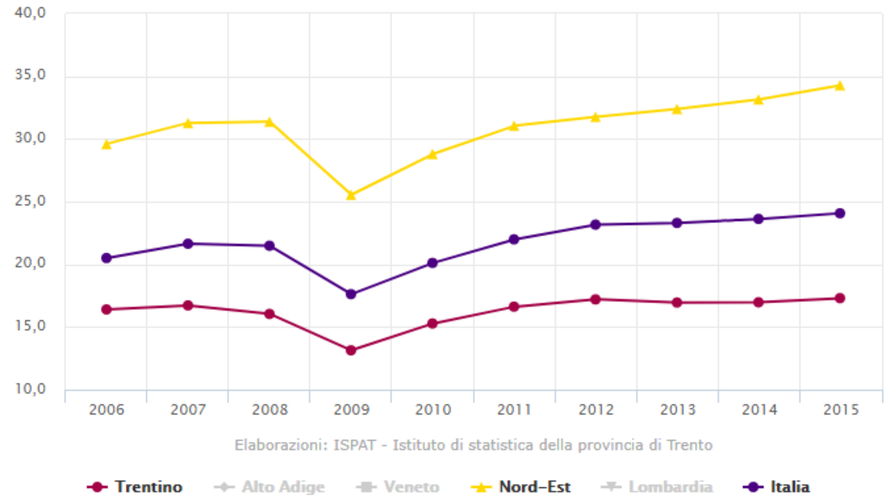
Figure 25: Firms' propensity to export[162] in Trento, North-East and Italy



Source: ISPAT

[159] This includes the following sectors: extraction, energy, water and waste, building, civil engineering, installations, sales and repair of motor vehicles.
[160] Measured at basic prices and estimated to be equal to 16.36 million of Euro.
[161] Agriculture accounts for the remaining 3.4% of the total value added.
[162] The propensity to export is calculated as the percentage of the total exports measured at current prices on the added value of agriculture and industry at current prices.

Figure 26: Percentage of exports in the manufacturing sector on GDP at current prices in Trento, North-East and Italy



Source: ISPAT

In terms of R&D expenditure and number of employees, the ICT sector is at the first place (with values equal to, respectively, the 70% and 54% of the total), followed by the manufacturing sector (with values equal to, respectively, the 25% and the 37%) with the prevalence of total expenditure in the mechanical compartment (9.5%) followed by chemistry (2%) and plastic (2%). The Rapporto Finale di Valutazione (2014) shows interesting trends in relation to the main areas of research and innovation[163] and technological platforms[164] of the local enterprises; during the period 2006-2012, 260 industrial research and pre-competitive development projects were presented in order to receive financial support, according to the Law 6/99, and the following aspects were underlined[165]:

- In terms of main areas of research and innovation taken into account, the largest share of the projects belongs to "ICT" (36.8%), followed by "Material Science" (10.5%), "Environment and management of the natural resources and sustainable production" (3%); "Biotechnologies, genomics and computational biology" (1%);

[163] According to the XIV Legislature, the following areas were take into account: "Environment and management of natural resources and sustainable production", "Biotechnologies, genomics and computational biology", "Neuroscience and cognitive science", "Science of Materials", "Evaluation of public policies", "Territorial governance and standards after the crisis", "ICT technologies".

[164] The technological platforms taken into account are: technologies for sustainable production (renewable sources of energy, green industry), environmental biotechnologies applications, food technologies for nutritional quality, traceability and healthiness of the products, technologies of systems and WEB services, human-machine interaction, sensors and embedded intelligence; technologies for enhancing the territory.

[165]The 24.6% of the projects presented cannot be considered part of any of the research and innovation areas and technologies platforms taken into account as 'priorities' in the XIV legislature.

- In terms of enabling technologies platform, the largest share of the projects belongs to the technologies for sustainable production (13.8%) and technologies related to web systems, human-machine interaction, sensors and embedded systems (8%);

The report underlines that the interaction between the enterprises and the public research system generates techno-scientific collaborations of high level, thanks to two main reasons: the participation of the University of Trento and of the Fondazione Bruno Kessler (FBK) to the main collaborative projects for innovation activities; a significant presence of collaborations with other Universities and Italian research institutions and, particularly starting from 2010, a number of international collaborations.

In order to better understand the relatively good performance in the indicators accounting for innovation and digitalisation and the presence of innovative projects in Trento, despite the absence of a solid manufacturing industry, the following paragraph is dedicated at getting more in depth into the institutional framework, describing the approach to innovation policy, including some important historical facts, the recent trends of policy strategies, the main players of the innovation system involved, the policy tools and the international network.

4.2.2. The institutional framework

The present paragraph is the result of 30 semi-structured interviews to relevant representatives of Trento's institutional framework. Table 40 summarizes the main players interviewed, specifying the relative function and organization.

Table 40: List of interviews by category, institution and department in Trento

Category	Institution	Department
Educational Institute	Istituto Tecnico Marconi	Director of the School
Government	Province of Trento	Past Research and Innovation policy councillor (today President of EURICSE)
Government	Province of Trento	Research and University Department
Government	Province of Trento	Knowledge Department
Government	Province of Trento	Economic development Department
Government	Province of Trento	Healthcare Department
Innovation agency	Trentino Sviluppo	Technological Innovation Promotion and Foreign Direct Investment
Innovation agency	Hub Innovazione Trentino (ex Trento Rise)	Team

Local Industrial Association	Confindustria Trento	President
Research centre	FBK	Area Innovazione e Relazioni con il Territorio
Research centre	FBK	Area Innovazione e Relazioni con il Territorio
Research centre	FBK	Area Innovazione e Relazioni con il Territorio
Research centre	FBK	Area Innovazione e Relazioni con il Territorio
Research centre	FBK	Area Innovazione e Relazioni con il Territorio
Research centre	FBK	ICT centre Director
Research centre	FBK	CMM centre staff
Research centre	FBK	Head of MT LAB CMM
Research centre	FBK	Head of Unit Embedded Systems
Research centre	FBK	Researcher Software Engineering
Research centre	FBK	Head Software Engineering
Research centre	FBK	Senior Researcher MPBA (predictive models for biomedicine and environment)
Research centre	FBK	Head of E-Health
Research centre	FBK	Head of Smart Optical Sensors and Interfaces
Research centre	FBK	Head of Applied Research on Energy Systems
Research centre	FBK	Head of Energy Efficient Digital Architectures
Research centre	FBK	Head of Data and Knowledge Management
Research centre	Create net	Managing Director
Research centre	FEM	In-house legal counsel
Telecommunication agency	Trentino Network	Director

University	University of Trento	Engineering Department

Source: author's elaboration

Special autonomy: a brief history

The special autonomy of Trento and of the neighbouring Provincia Autonoma di Bolzano, forming together the Autonomous Region of Trentino Alto-Adige, dates back to an agreement between Italy and Austria, signed in Paris on the 5th of September 1946 by the then Italian Prime Minister, Alcide Degasperi, and the Austrian Minister of Foreign Affairs, Karl Gruber. The text of the Statute became Constitutional Law No. 5, the 26th February 1948[166]. The Autonomy gives to the Province direct legislative, administrative and financial jurisdiction in specific areas, including education, health, industrial policy, transport, University and tourism, managing within the Province the 90% of direct and indirect income collected. "Autonomy allows the province to plan its own development and to transform the Public Administration into a system for organising and providing services, able to adopt the same approach of the best private enterprises" (PAT, 2010, p. 7). Starting from the Sixties, the Autonomy made it possible for the Province to develop a solid research and innovation system, a long time before innovation policies started to become fashionable among policy makers and academics.

Bruno Kessler, who governed the Province as President of the Provincial Council between 1960 and 1974[167], has been one of the protagonists of this strategic plan, aimed at recovering an economic depressed area through strong investments in knowledge and culture.

His programme was based on three main priorities: to stimulate economic development, reducing the inequality between urban and peripheral areas and promoting education and culture as priority actions; to close the gap in terms of economic and cultural development with the neighbouring regions, in order to discourage the exodus from the rural and periphery areas; to develop the urban centres and raise the local cultural identity. In order to reach these purposes in the long term, it was necessary to implement an adequate cultural policy, based on the development of research centres able to raise the overall cultural and education level of the population, to open the city to the international network and to stimulate innovation processes on the overall territory.

Table 41 summarizes some main stages of this process. In 1957, Bruno Kessler became the President of the Agrarian Institute of San Michele all'Adige, today Fondazione Edmund Mach (FEM), which plays an important role in the development of the agriculture sector in Trento. In 1962, the "Istituto Trentino di Cultura (ITC)", today known as FBK, was established; it was initially born as the incubator of the University, which, according to Kessler's view, had a strategic function for the development of the territory. From the beginning, ITC included the Italian-German Historical institute, with the purpose to combine the

[166] Later on, a Second Statute of Autonomy was adopted in 1972.
[167] During this period he was contemporarily President of the Province, of University and of the Istituto Trentino di Cultura; also due to this high concentration of power, his policy was able to introduce significant changes.

Italian and the German cultures, the Institute of Religious Science, the Institute for Scientific and Technological research and a centre for Research and Innovation.

"Cultural development is a necessary condition for the economic growth of the whole community (...) I recognize the deep value of culture and most of all, I feel that our people, the men of our valleys, need to be more supported: cultural development must be necessarily the result of our primary attention to these sectors. I am sure that our people have the moral capacity and integrity to become an important resource for the entire community" (own translation, Bruno Kessler in Marcantoni et al., 2005, p.803-804).

From the beginning, the ITC was characterized by a specific legal jurisdiction, benefiting of a large financial support from the Province. In 1962, the Istituto Superiore di Scienze Sociali was founded, legally recognized in 1966, and approved through a formal status in 1967. In 1972, "Istituto Superiore di Scienze Sociali" became "Libera Università degli Studi di Trento" and in 1982 "Università Statale degli Studi di Trento". Starting from 1973, in line with the initial project, the ITC started to specialize in scientific and technological research areas, becoming the "Istituto di Ricerca Scientifica e Tecnologica" (IRST), with a particular vocation in natural science; from the beginning, the centre invested in particular research fields that were not yet developed in Italy: it became the incubator of the Faculty of Material Science and Engineering, specialized in Physics of the surfaces, Advanced Materials Technology and Applied Electronics. Starting from 1985, it became the first Italian institute specialized in *artificial intelligence*, thanks to Luigi Stringa, an Italian physicist well known in this field of research[168]. There have been two main development stages of the institute: the first stage, characterized by the predominance of robotics as main research area; a second stage, which sees the shift towards more intensive ICT-related research activities, as a result of the growing competition of the U.S. and Japan in the field of artificial intelligence; this second stage of development gave the start to the great expansion of the ICT eco-system in Trento.

From the beginning, the institute was established as a centre for local development, which had to maintain a specific 'applied research' vocation, in contrast to the 'theoretical approach' of the University:

"Assuming that the institute must remain a centre of applied and not theoretical research, it is necessary to stress the importance of IRST for the economic and industrial development of our Province (...) I'd rather say that this virtuous process will never be able to occur without the support of a research institute" (own translation, Bruno Kessler in Marcantoni et al., 2005, p. 806).

In 1993, the Statute was revised, with some significant changes in the organizational model: on one hand the institute was autonomous in choosing its research lines; on the other hand, it was responsible to

[168] One of the first artificial intelligence projects developed in Italy has been the "Advanced Model of Artificial Intelligence" (MAIA), an integrated platform provided with a distributed intelligence and robot; the model was supported by a complex network of powerful calculators and was based on three main parts: a 'concierge' able to answer with a 'natural speech' to questions concerning the institutes and its purposes; a robot, with a perfect knowledge of the map of the corridor and of the rooms of the institute, offering the possibility to guide the visitors in the different rooms and in the library; a second robot, the responsible of the library, with a microphone, a keyboard, a camera, a monitor and a written summary of the information requested on the books. This model has been one of the first examples of artificial intelligence experiments, combining different approaches to artificial intelligence: from voice recognition to vision technologies, natural language, knowledge representation systems and inferential reasoning.

monitor the results of the research activities, in relation to the amounts of funds invested. During the Nineties, the ITC started to be involved in important European projects and a partial self-financing policy was introduced, aimed at increasing the expenditure capacity of the institute which was already very much supported by the Province. At the same time, also the University started to go through a strong process of internationalization, being one of the first Italian Universities to develop co-tutelle programs with prestigious European universities, starting to become attractive for foreign students.

Trento's institutional evolution highlights the early development of a strategic policy vision thanks to which the Province, despite the presence of geographical disadvantageous conditions, has been able to "invest in culture and education, making Trento a centre of production, interpretation and animation of knowledge and science, favouring the introduction in the big national and international circuits of intelligence and innovation" (own translation, Marcantoni et al., 2005, p.809).

Table 41: Main historical facts of Trento's Autonomy

Date	Historical Fact
1946	Beginning of the Autonomy
1960-1974	Bruno Kessler's governance
1957	The constitution of the "Istituto of San Michele all'Adige"
1962	The constitution of the "Istituto Trentino di Cultura (ITC)"
	The constitution of the "Istituto Superiore Scienze Sociali"
1972	"Istituto Superiore Scienze Sociali" becomes "Libera Università"
1973	ITC-IRST becomes a centre of artificial intelligence (Luigi Stringa)
1982	"Libera Università" becomes "Università degli Studi di Trento"
2007	ITC and Istituto San Michele all'Adige become respectively Fondazione Bruno Kessler (FBK) and Fondazione Edmund Mach (FEM)

Source: author's elaboration

Evolution in the approach to innovation policies

The crucial importance given during the Sixties to research as a source of local development must be understood in the context of the so called 'science driven' approach to innovation policy; in line with the neoclassical 'linear approach' to innovation, based on the assumption of investing in knowledge transforming automatically into innovation, a high amount of public funds has been invested in education and research activities. This position stimulated very soon a debate concerning the effective utility for the community of such strong investments in research activities: on one hand the scientific world supported the idea that Trento could achieve a high international visibility, stimulating the creation of a new generation of high-tech local entrepreneurs; on the other hand, the industrial players underlined the need for the public authority to focus on 'correcting market failures', supporting the propensity of the local productive system to innovate, rather than trying to acquire the leadership as a centre of excellence in scientific research (Salvatori, 2011). During the years, the conflict between these two opposite positions increased, due to the lack of convergence towards a unique model, able to reconcile both expectation and needs.

Moreover, in recent years, in parallel to the international economic crisis which reduced the central government financial aids, the need to define the specific sphere of regional competence in the area of scientific and technological research became more and more urgent. For these reasons, in 2005 it began a period of structural reform[169] of the research and innovation system aimed at reducing the gap between the research and the entrepreneurial systems, improving the impact of the research centres on the territory. Three important elements were introduced: the formalization of the concept of 'provincial system of research', characterized by the interaction between the University, the research centres and the enterprises; the adoption of financial mechanisms supporting innovation activities; the transformation of the public research centres, ITC-IRST and Istituto San Michele All'Adige, into private foundations.

The reform was aimed at defining the specific context of intervention of the provincial policy in a multi-level system, meaning that the players operating in research and innovation activities could choose the adequate balance between the different sources of funding (public, private, local, national and international), according to the objectives to pursue (Salvatori, 2011). Finally, the Provincial Law of the 2nd August 2005, n. 14, transformed ITC-IRST and the "Istituto Agrario di San Michele all'Adige" respectively into FBK and FEM, private non-profit entities, with public interest. In particular, the Law assigns to the foundations the mission to promote and develop "research in sectors of interest for the local development".

The foundations are *"supposed to give importance to the activity of transmission of knowledge from the research world to the economic system, favouring the acquisition, the circulation of information and the availability of specific technical competence, also at local level" (own translation, PAT, 2005,).* In line with these general principles, the Statute (Art. 1) defines the mission of the foundations as players for scientific and technological development and for the *"promotion of a widespread capacity to stimulate innovation, in*

[169] One of the protagonists of this age of reforms is Lorenzo Dellai, who took great inspiration from the political vision of Bruno Kessler and was at the government of the Province between 1999 and 2012. He made many efforts in orienting the Province towards the construction of an ICT ecosystem.

order to favour the growth of Trentino, with an adequate technological transfer and qualification of public structures and administrations" (own translation, PAT, 2005).

The other relevant policy tools which help to understand the distinctive characteristics of Trento's innovation system is the Law n.191/2009 which gives Trento full autonomy in designing and implementing aid schemes, infrastructures, education and training and full autonomy in the design and implementation of technology and innovation policies. Finally, the Law 6/1999 contains the conditions and modalities for enterprises to receive subsidies and incentives for applied research, to establish temporary research contracts and to employ researchers in a company; only enterprises which are fully established in Trento or that have at least a production plant can benefit of these incentives; these support measures are given for research centres as operative units of the enterprises, in order to assist knowledge and human capital transfer from public entities to private ones. This law has the purpose to attract firms to locate their headquarters and production plants within the Province, in order for the overall territory to benefit from the 90% of direct and indirect income collected within the Province[170].

As a result of the need to move from a 'top-down science based' approach to innovation policy to a 'bottom-up' approach based on 'entrepreneurial discovery' and direct imitation, in 2016 Trento presented the final document defining the Provincial strategy for Smart Specialization (RIS3), presenting the investment priorities areas to support "smart, inclusive and sustainable growth". In this context, the strategy of the Province has been to concentrate and invest the available resources in four main competitive areas: agrifood, mechatronics[171], energy and environment and quality of life. These are considered not separate but synergic sectors, favouring cross-fertilization processes through the following KETs: nanotechnologies, micro and nanoelectronics, smart materials, biotechnologies, advanced manufacturing and photonics[172].

The players of the innovation system

The Province of Trento operates as an actor of the innovation system through four main Departments: the Department of University and Research, youth policies, equal opportunities and cooperation; the Department for the programming and coordination of innovation and for the transversal and pervasive sector of ICT; the Department of Knowledge, in particular through the Office for University and Research; the Department for economic development, in particular through the Provincial Agency for Incentive to the Economic Activities (APIAE), which manages subsidies and financial aids to the enterprises.

On the territory, Trento's research system is very articulated and is characterized by a high level of specialization in different techno-scientific disciplines, with over 40 research centres and international groups of research. The University is present with 10 departments, 3 Centres of Athenaeum, 54 classes, 570

[170] An interesting analysis of the impact of R&D incentives of the Law 6/99 on firms' performance in Trento has been provided in Corsino et al. (2012).

[171] The decision of the policy makers to support the creation of a cluster in mechatronics has been the result of an actual process of 'entrepreneurial discovery'; in fact, the traditional cluster of mechanical subcontractors of large firms, like Michelin for example (on the territory between 1927 and 1998), in the following years started to shift towards mechatronics. Therefore, the Province supported their request creating a department of mechatronics at the University of Trento and a cluster in mechatronics, the 'Polo Meccatronica'.

[172] ICT is included as a KET, due to its transversality in all the sectors.

teachers, researchers and 16.260 students in 2013. According to the CENSIS report 2017/2018, the University of Trento is ranked at the second place among the Italian medium Athenaeums[173].

FBK plays a fundamental role in the innovation system; as already mentioned, it inherits the activities of ITC - IRST, and today articulates in two main areas, a scientific one and a humanistic one, with 7 main research centres[174]; it has more than 350 researchers and 220 doctoral students, post doctoral students and visiting professors.

FEM inherits the activities of the Istituto Agrario di San Michele all'Adige, founded in 1874, developing scientific research activities, education and training, applied research, consulting and service activities to enterprises in the agriculture, food and environment sectors, thanks to over 350 employees and three dedicated centres ("Centro per la Ricerca e l'innovazione, "Centro per l'Educazione e l'Istruzione" and the "Centro per il Trasferimento Tecnologico").

Hub Innovation Trentino (HIT) is a no-profit corporate consortium that promotes the research results and innovation of the system in order to foster local business innovation and development. HIT inherits and extends part of the activities of Trento Rise, which was created in 2009 from the University of Trento and FBK and ended in 2015; Trento Rise has been one of the partners, with Telecom Italia and the Engineering company, of the Knowledge Innovation Community (KIC) in ICT, achieving the unique ICT node of the European Institute of Innovation and Technology (EIT) digital. In July 2015, the Pluriannual Programme of Research for the XV Legislation underlined the need to create a new agency, able to support effectively the economic development of Trento and its international network. Starting from September 2015, HIT has been established as a strategic and systemic actor with the purpose to join together the University of Trento, FBK, FEM and Trentino Sviluppo and strengthening the activity of technological and knowledge transfer from the research centres to the enterprises, both at local, national and international level, centralizing all the strategic initiatives in sectors like research and innovation (national technological cluster, KIC and European PPPs for Innovation).

EIT digital has a headquarter in Trento, inside FBK, as a catalyst of innovation activities, with the mission to support through ICT, the transformation of Trento in a knowledge competitive and dynamic ecosystem, focusing on sustainable development and quality of life, integrating education, research and business, and working in synergy with the other nodes of the network[175] and with the other partners of the Italian node[176]. The "Consiglio Nazionale delle Ricerche" is characterized by some territorial hubs of National Institutes: the institute for photonics and nanotechnologies, the institute for biophysics, the institute for electronics and magnetism, the institute for the enhancement of wood and other arboreal species, the institute for science and cognition technologies and the Centre for Proton Therapy.

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[173] See: http://www.censis.it/17?shadow_pubblicazione=120571

[174] For further details see the paragraph "FBK as an actor of the innovation system".

[175] The nodes of the network are Berlin, Paris, Helsinki, Eindhoven, Stockholm and London

[176] The partners of the node are: Telecom Italia ed Engineering (core partner), Centro di ricerca Fiat, STMicroelectronics, Università di Bologna (Alma Mater Studiorum), Centro Nazionale di Ricerca (CNR), Politecnico di Milano, Politecnico di Torino e Scuola Superiore Sant'Anna di Pisa (associate partners).

Moreover, the territory is characterized by the presence of private agencies, participated by the Province for 100%, which coordinate, guide and develop enabling infrastructures for the development of projects and entrepreneurial ideas.

Trentino Sviluppo is the 'in-house' agency of the Province, in charge of the Province's real estate management, facility management services, supporting start-up enterprises, managing the 6 Business Innovation Centres (BIC) and attracting foreign investors from abroad through Foreign Direct Investments (FDI) activities. Finally, Trentino Network supports the telecommunication networks and Informatica Trentina, the development of ICT skills for the management of the overall information system.

Trento has also developed many initiatives with the purpose to stimulate technological and knowledge transfer to the local enterprises, favouring the development of new entrepreneurship on the local territory. Among these initiatives:

- The 6 BIC (Rovereto, Trento, Pergine, Mezzolombardo, Borgo Valsugana, Pieve di Bono) hosting a total of 85 enterprises; the BIC includes Polo Meccatronica and Progetto Manifattura as main projects.
- Some programs for incubators of new enterprises, managed by public agencies or PPPs like, for example, Industrio and Progetto Manifattura[177].

Main projects on the territory

Table 42 summarizes the main innovation projects developed by the Province with a major impact on the territory. The most relevant projects in terms of amount of funds invested and strategic role on the territory are Progetto Manifattura and Polo Meccatronica, with an amount of funds equal, respectively, to 48 and 80 million of Euro. The aim of Polo Meccatronica and Progetto Manifattura is to create physical 'hubs', where, thanks to the support activity of Trentino Sviluppo, the industry, the education and innovation system, collaborate to develop innovative projects in two of the four strategic sectors identified by the Province in the context of the RIS3: mechatronics and renewable energy. The purpose is to overcome the gap between education, knowledge transfer and the enterprise system, increasing the technology/knowledge transfer on the territory and improving the innovation capabilities of the firms inside the parks; both hubs have attracted the interest of important national key players in the mechatronics and renewable energy sectors, like, Bonfiglioli, Ducati Energia, Dana, Carl Zeiss, which located their research centres inside the Polo and many innovative high-tech start-ups and private accelerator Industrio Ventures, the first Italian accelerators supporting the development of 10 high-tech startups[178].

[177] These projects will be described more in details in the following paragraphs.

[178] Among these Melixa, which developed hive remote monitoring systems, Doctor Wine Tech, a highly innovative bottling system reducing the level of additive and maintaining the good properties and the taste of wine, Bikee Bike, an electrical engine for bicycles, Meccatronicore, specialized in 3D printing prototyping, Lock and Charge, which developed a high technological alarm system, making any small voltage electric vehicle instantly sharable, protected and charged, Nova Labs, a hardware and software system supporting enterprises in the development of innovative robots with a plug and play approach; Brainsomeness, a sensor system monitoring speed, machine running, acceleration, brakes and heartbeats; Mirnagreen, a technology for the extraction, production, distribution of bio-active substances for preventing and treating diseases of people, animals and plants; Bermat, an innovative modular that is configurable on line, to create totally customized sport cars.

"This is the largest industrial policy investment of our Province; the aim is to build the 'new Factory of the Future" (Alessandro Olivi, Vice President of the Province in Polo Meccatronica Instant Book, 2017).

Also Progetto Manifattura has attracted significant players in the renewable energy sector, like RTR Energy, Ardian and Gruppo Margherita, which recently signed a partnership with the intention to build a solar, wind power and hydroelectric power station monitoring remotely all the other plants of the country[179].

Table 42: Main innovation projects in Trento

Project	Duration	Budget	Main players	More Info
Polo Meccatronica	2013-2020	80.000.000,00 €	PAT and Trentino Sviluppo	http://www.trentinosviluppo.it
Progetto Manifattura (Rovereto)	2015-2018	48.522.151,20 €	ERDF funds and PAT	http://www.opencoesione.gov.it/
Strengthen research, technological development and innovation	2013-2020	ERDF Funds, €27.438,479 (50.5% from the EU)	ERDF funds and PAT	http://www.europa.provincia.tn.it
Promote SMEs competitiveness and Agriculture	2013-2020	ERDF Funds, €13.855,182 (25.5% from the EU) €10.867,024	ERDF funds and PAT	http://www.europa.provincia.tn.it
Green and low carbon economy	2013-2020	ERDF Funds €10,867,024 (20% from the EU)	ERDF funds and PAT	http://www.europa.provincia.tn.it
Seed Money	2013-2020	Euro 150.000 fund allocation	ERDF funds and PAT	http://www.trentinosviluppo.it/public/file/bandi/78f2f06b9cb468688def128cc5f0f275.pdf
ODT – Open data in Trentino	2012-2016	n.a.	PAT,Informatica Trentina, Trento Rise	http://www.innovazione.provincia.tn.it/opendata

Source: author's elaboration drawing on RIM (2016)

[179] See also the following link: https://www.pressreader.com/italy/corriere-del-trentino/20170321/281852938389861

The National and International network

Trento positions well in the national and international circuits of scientific research. Concerning the KIC, besides hosting the unique co-location centre within the consortium ICT node of EIT, after winning the KIC on ICT in 2014, Trento is actively part of an international network of strategic European projects, involving relevant active businesses on the territory. In 2014, it participated to the KIC on "Healthy Living and Active Ageing" and on "Raw Materials", achieving in the latter case the role of core partner, in collaboration with FBK, the University of Trento and Trentino Sviluppo[180]; it also applied for the KIC on "Food4future" with the support of FEM, and to the call "Added Value Manufacturing". According to many interviewees, the participation to these projects contributed substantially to the creation of local hubs in mechatronics and renewable energy.

In relation to the European PPPs for innovation, Trento is part, through HIT, of the European consortium "Smart Cities and Communities[181]", participating to "Active and Healthy aging", in particular in relation to the Action Group C2 on "Development of interoperable independent living solutions"; moreover, through FEM, it has a strategic role in the European Partnership for Innovation on "Sustainability and productivity in Agriculture"; University of Trento and the FBK are part of the European Flagship on Graphene with the participation of FBK as a partner, through the Applied Research on Energy Systems (ARES) unit; to the European Energy Research Alliance (EERA), to N.ERGHY, research grouping in JTI Fuel Cells and Hydrogen, and to the ESEIA, European Sustainable Energy Innovation Alliance.

As for the participation to the 7th Framework Programme[182], Trento achieved positive results at national level:

- The research centres and the enterprises applied for 1.700 proposal in the Seventh Framework Programme, receiving funds for the 21.7% proposals presented, for a total amount 120 millions of Euro, in cooperation with national and European partners;
- Most projects presented belong to the ICT thematic area, covering almost a half of the total winning projects (178), and funds (61.7 millions of euro). In terms of number of projects presented, Marie Curie Actions counts the highest level, followed by the projects financed by the European Research Council (ERC) and by the Conjunct Technological Initiatives, Health, Research for SMEs, Transports and Environment;
- The University of Trento shows the best performance at national level in terms of applications to the European Research Council (ERC), receiving the largest amount in the shift from the Seventh Framework Programme to Horizon 2020. A total of 19 projects for almost 25 millions of Euro;
- The players of the research system shows also positive results in terms of researchers' mobility-Marie Curie Actions, with over 60 active projects on the different types of schemes, with an experience of COFUND, managed and co-financed from the Province;

[180] The Italian-Spanish node is headed by ENEA.
[181] http://smartcities.ieee.org/news-bulletin/december-11-2014/the-ieee-smart-cities-initiative-in-trento-italy.html
[182] http://cordis.europa.eu/result/rcn/155558_it.html

- The participants to the Seventh Research Programme are mainly public players, with over the 40% of foundations and research centres, one/third coming from the University of Trento; the level of participation of SMEs is still low (18% of the total), but shows an increasing trend;
- Other important projects in which Trento is involved regard the Internet of Things[183] (IOT), STARTIFY7[184] and OPENDATA[185] and S3-4AlpsClusters, with the aim to increase the impact of the RIS3 implementation within the Alpine Space Area[186];

Concerning the National Technological Clusters, HIT is part of "Cluster Tecnologici Nazionali" (CTN) "Technologies for Smart Communities"; FBK of CTN "Smart Manufacturing", FEM of "Agrifood-CL.AN" and "Chimica Verde-SPRING". At the national level, Trento is partner of "Cluster Nazionale Fabbrica Intelligente" and of the "Cluster Agrifood Nazionale" (CLAN).

FBK as an actor of the innovation system

FBK is at the frontier of knowledge and research on technological innovation, with a combination of scientific activities structured in four main centres: the Centre of Information and Communication Technology (ICT), focused on some main key areas of information technology, the Centre for Materials and Microsystems (CMM), operating in materials and interfaces, devices and microsystems and integrated systems; the Center for REsearch And Telecommunication Experimentation for NETworked communities (CREATE-NET), specialized in computer networks and telecommunications; the European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT), focused on nuclear physics and related research areas. In addition to these, EIT co-innovation ICT Lab is the main link to the European network of strategic partnerships in the national and European ICT arena, collaborating with public and private partners at national level[187]. Finally, in order to facilitate the relationships both between the units of the foundation and between the foundation and the relevant stakeholder at the local, national and international levels, Area Innovazione e Relazioni con il Territorio (AIRT) is the intermediary unit which is involved in facilitating technology idea sharing with the enterprises and other organizations on the territory, promoting training activities for young students of the local education system[188] and managing partnerships, contracts, funding raising and other technological transfer activities[189].

[183] http://www.unify-iot.eu/
[184] Start-up summer school of ICT for young aspiring entrepreneurs, see: http://www.startify7.eu/;
[185] With the network FINODEX at European level: http://www.finodex-project.eu/
[186] http://www.alpine-space.eu/projects/s3-4alpclusters/en/home
[187] EIT core partners are: Engineering Ingegneria Informatica, FBK, TIM, University of Trento; the affiliate academic partners as Alma Mater Studiorum Università di Bologna, Consiglio Nazionale delle Ricerche, Politecnico di Milano, Politecnico di Torino; the affiliate industrial partners are: CEFRIEL, Centro Ricerche Fiat, Poste Italiane, Reply and STMicroelectronics.
[188] FBKJUNIOR is the name of the project, developed starting from 2008, aimed at promoting the value of scientific research as a profession through partnerships with institutes and entities, shared projects, hosting students for internships and participating to cultural activities like "JuniorLesson"
[189] The technological transfer and knowledge sharing activities have gradually shifted from AIRT to HIT, which has been recently recognized as the strategic actor on the territory, managing technological transfer and knowledge sharing activities as a 'systemic' actor.

According to ANVUR (2016), the ICT centre in FBK is at the first place among 24 research centres in Information Science and Engineering, and at the second, in terms of quality of its scientific production. The following paragraphs discuss in details the main approach to innovation and knowledge and technology transfer adopted by the ICT and CMM centres.

CMM Centre

The CMM centre is the applied research centre that operates in the following areas of science and technology: materials and interfaces, devices and microsystems and integrated systems. The centre is composed by the following research units: Micro-Nano Facility Lab, (MNF), Micro-System Technology (MST); Functional Materials and Photonics Structures (FMPS), Integrated Radiation Imagers and Sensors (IRIS), Applied Research on Energy System (ARES) and 3D Optical Metrology (3DOM).

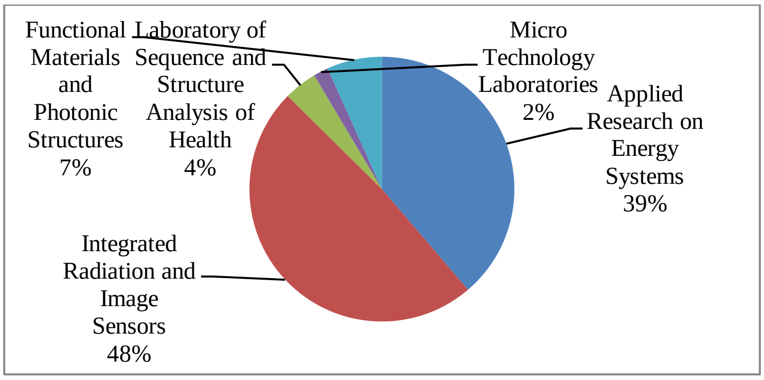
Specifically, IRIS, MNF Lab and ARES units support the CMM centre in the design and fabrication of microsystems with heterogonous techniques of material integration of structured micro-nano materials and silicon and macro-system for energy systems.

Taking into account the overall projects developed by the CMM centre between the 1st January 2010 and the 31st of October 2016, with an entry for FBK higher or equal than Euro 250.000,00, 25 main projects are identified, for a total revenue of € 13.781.820,67[190]. I have divided the revenue of the overall projects by technological area and main counterpart.

Figure 27 shows the distribution of the projects' revenues by main technological area. As can been seen, the most profitable unit has been IRIS, generating 48% of the total revenue, followed by ARES (39%), FMPS (7%), the Laboratory of Sequence and Structure Analysis of Health (4%) and MT Lab (2%). Taking into account the distribution of the projects' revenues by counterpart (Figure 28), most of the total revenue derives from grant agreements with the European Commission (57%), followed by grant agreements with the Province of Trento (18%), R&D services with industrial partners (12%), grant agreement with the Ministry (10%) and a collaboration project with the National Institute of Nuclear Physics (3%). In the context of these European projects, the centre as a whole participates to an important European flagship, the KIC on raw materials, previously mentioned, which gives the centre a high prestige.

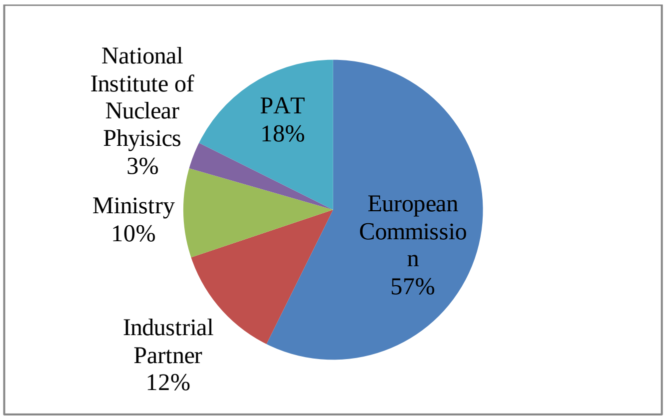
[190] This aggregate information has been taken from FBK's internal database.

Figure 27: Distribution of the projects' revenues in FBK by unit[191]



Source: author's elaboration

Figure 28: Distribution of the projects' revenues in FBK by counterpart[192]



Source: author's elaboration

IRIS unit

IRIS is focused on the research and development of advanced solid-state sensors, either using dedicated technology processes or state-of-the-art complementary metal-oxid-semiconductor (CMOS) technologies, with special and fully customizable features[193]. In simple terms, the research activity of this strategic unit is focused on the development of microchip for smart and integrated sensors. These devices have potential applications for different activities: physical experiments, medical diagnosis, biology, monitoring of environmental processes, industrial control and security.

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[191] The graph takes into account the overall projects between 1st January 2010 and the 31st December 2016, with total revenues for the foundation equal or higher than 250.000 Euro. This criterion was suggested as significant during an interview with a scientific researcher.

[192] The graph takes into account the overall projects between 1st January 2010 and the 31st December 2016, with total revenues for the foundation equal or higher than 250.000 Euro. This criterion was suggested as significant during an interview with a scientific researcher.

[193] Single-photon avalanche diodes, silicon photomultipliers and strip detectors, custom image sensors and infrared and terahertz sensing devices are among the expertise of the research unit. Their solutions portfolio start from the study and physical design of the sensor device, the tuning of the fabrication process and its implementation, the design and simulations of integrated electronics, up to the development of module- and system-level electronics and optics with complete electrical and optical characterization.

"Single-photon avalanche diodes make it possible the so called '3D sensing capacity', that is the capacity of robots to perceive the surrounding environment thanks to highly sophisticated algorithms; one of the most important applications of this technology is the autonomous driving car; the problem of introducing sensing capacity in machines is one of the most difficult tasks, which high-tech research centres all over the world are working on; the challenge is to make this sophisticated technology competitive for the mass market; it will be for sure the next technological revolution" (Head of IRIS unit, FBK).

In the context of the industrial collaborations, this research unit counts five strategic collaborations with industrial partners for R&D services activities for the production of advanced sensors in the industrial and biomedical sectors, most of which are extra-European[194].

"One of our partners is a Japanese multinational company which has recognized in FBK the capacity to provide innovative sensors of high quality and reliability standards, also thanks to the support of one of the most important clean rooms for the production of silicon sensors and Micro Electro-Mechanical Systems (MEMS)"(Head of the MNF unit, FBK).

The MNF unit supports the IRIS unit in the fabrication, testing and analysis of materials and maintenance of the specific plants for the labs of the centre; the fabrication area includes two main clean rooms: the first is mainly dedicated to the production of silicon sensors, in particular related to radiation sensors; the other one is dedicated to the development of MEMS[195]. The testing area manages the instrumentation and laboratories for the control of the devices produced from an electric point of view, including also the instrumentation for optical devices. Moreover, the MNF lab supports all the other units of the centre, developing research activities on the KETs: nanotechnologies, microelectronics, advanced materials, photonics, and industrial biotechnologies for advanced manufacturing systems. Moreover, the MNF lab manages the technological and knowledge transfer activities in the final phases of the partnership with the company.

One of the most significant projects developed in collaboration with the IRIS unit concerns the development of the Silicon Photo Multiplier (SiPM)[196], a solid-state single-photon-sensitive device built from an avalanche photodiode for diagnostic application and medical imaging able to replace the conventional Positron Emission Tomography (PET). FBK is one of the unique research centres able to develop this technology, attracting strategic collaborations with important extra-national groups. Another technology having a great success is the design and the preliminary electro-optic testing of a sensor for X-ray imaging applications. This technology has a great potential in the field of advanced analysis of materials.

[194] One of the most strategic partnerships is with Horiba Ltd, the Japanese world leader in the chemical analysis sector for several industrial segments including automotive, biomedical and environmental sectors. This collaboration, which began eight years ago, recently renewed, has been the result of Horiba's need to find a partner able to design and produce the next-generation of sensors to be integrated in their products.

[195] The centre outsources the fabrication of silicon sensors to different CMOS foundries on the territory; this is indicated as one of the main areas having a local impact on the territory.

[196] This technology is used for the improvement of the MRI techniques' quality.

ARES unit

ARES is a research unit, more related to applied research, which has the aim to promote research and innovation on new energy solutions to local and international industrial partners and public entities.

"The underlying philosophy of this unit is the conviction that efficient and effective implementation of innovative energy solutions will be crucial to balance our ecological footprint, granting a sustainable future" (Head of ARES unit, FBK).

There are three main lines of research which they are working on (Figure 29):

- *Concentrated Solar Power (CSP)*, a technology that produces electricity by concentrating sunlight onto a small area. A major advantage of the CSP plants is that they generate power reducing carbon dioxide emissions, especially during grid peak demand. Therefore, CSP can potentially displace the use of fossil fuel plants that emit the greenhouse gases causing climate change. Nowadays, large-scale research efforts are necessary to improve performances of CSP technology, in order to reduce technology development costs and foster a global market penetration, making this technology profitable and compatible as an alternative source of clean energy.
- *Hydrogen Technologies*, the production and use of hydrogen for different applications. In the energy domain, hydrogen is an ideal energy storage medium that could have an important role in preventing climate changes. In fact, some innovative hydrogen technologies are carbon neutral and could drive a possible future hydrogen economy, supporting the environment, the climate and the transition to a sustainable society.
- *Smart Buildings & Communities*, a new way to build and manage houses in order to make them more efficient and sustainable, integrated with renewable energy sources locally available in a reliable and secure way. It is fundamental to address this sector improving our buildings in environmental and sustainability profiles. At the same time, it is important to raise awareness in our communities regarding energy saving methodologies: in collaboration with households, schools, enterprises, governments and no-profit organisations, it could be possible the creation of smart communities able to educate citizens to use less energy, reducing energy bills for the environment's improvement.

During 2015, ARES has supported the prosecution of the activities in the project 'Flagship Graphene', where the position of FBK-CMM consolidated in the new project CORE1, starting from April 2016. FBK is involved in GRAPHENE CORE#1 with 4 work packages, continuing its activity in the Energy and Nanocomposites topics and adding new activities in Photonic and Wafer scale system integration. In 2015, some explorative activities started in cooperation with the unit Embedded Systems (ES) of the ICT centre, with which they are developing projects concerning 'smart grid' and battery flux; moreover, they are participating to a project, CONTEST, in collaboration with the Province of Trento based on Concentrated

Solar Power (CSP) through the Stirling engine technology. Another prestigious project to be mentioned is SIQURO[197], financed by the Province of Trento for the development of new photonic optical devices[198].

"The challenge of this unit is to integrate 'smart systems' into 'energetic systems'; in the context of a growing integration between the 'hardware' and the 'software' knowledge domains, we are seeking to reinforce our collaboration with the ICT centre, in particular with the unit of 'Embedded System'[199]" (Head of ARES unit, FBK).

Figure 29: Research Lines conducted in ARES, FBK

Source: ARES (2016)

ICT Centre

The ICT Centre follows three main "Research Lines" (RL) with three main "High Impact Initiatives" (HII) (Figure 30).

The RL are group of units and research projects with different expertise, but sharing some common themes and challenges:

- Cognitive Computing, which analyzes systems that naturally learn and interact with humans in complex environments;
- Complex Data Analytics, systems able to analyze big data and transform the restless streams of data in value, knowledge and decision capability;
- Adaptive, Reliable and Secure Systems, reliable and secure systems that operate in open, distributed, dynamic and unpredictable environments;

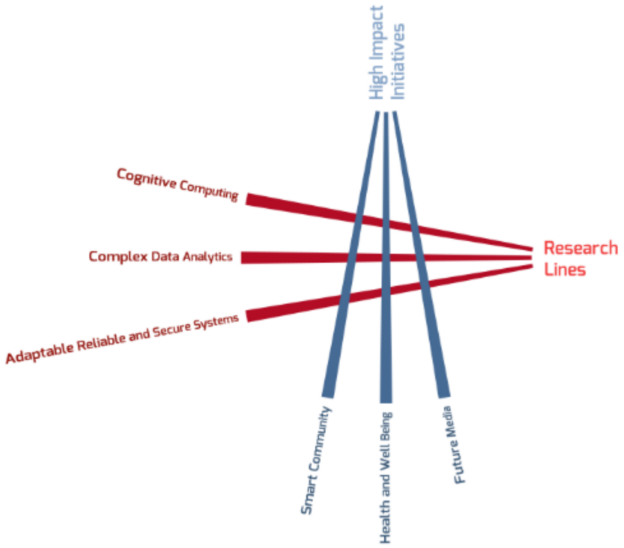
The RL are aimed at maintaining and reinforcing the vertical scientific competences, launching transversal projects in support of the following the HII:

[197] FMPS is the unit mainly involved in this project.
[198] This project makes it possible for FBK to collaborate with centres of scientific excellence like III-V labs in Paris and ETH in Zurich.
[199] FBK collaborates with Green Energy Storage, an innovative start-up developing a technology which is able to store a great capacity of clean energy from renewable sources like wind and sun, through a new organic flow battery that will provide energy savings of both private home and small businesses.

- Smart Community, in order to improve tailored services for the citizens, with new interactive ways of communication with the government, new ways of service delivery to citizens, and new forms of collaboration;
- Health and Wellbeing, for the digitization of health services;
- Future Media, for the management of media contents, text, images, video, semantic annotations in complementary and integrated ways.

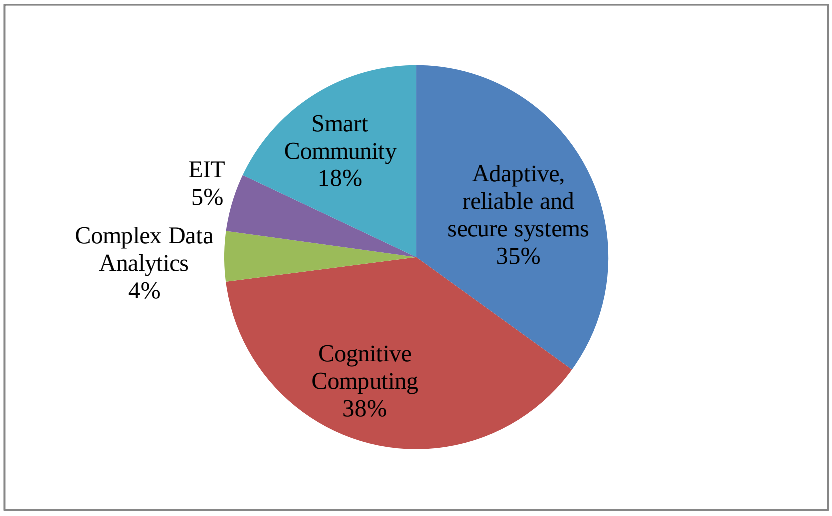
Figure 31 shows the distribution of the revenue of the projects developed by the ICT centre between the 1st January 2010 and the 31st of December 2016 with total revenue for each project higher or equal to Euro 250.000, by technological area. The total 39 projects yielded a total revenue of € 20.303.192,18. A relevant share of the total revenue is generated by the RL of Cognitive Computing (38%), followed adaptable, reliable and secure systems (35%), the HII in Smart Community (18%), EIT (5%) and Complex Data Analytics (4%). In terms of type of contract and main partners involved (Figure 31), most of the total revenues derives from grant agreements with the European Commission (78%), followed by grant agreements with the Province of Trento (9%), EIT (7%), R&D services with industrial partners (3%), grant agreement with ECSEL Joint Undertaking (2%) and R&D services with a University (1%).

Figure 30: Research Structure in ICT, FBK



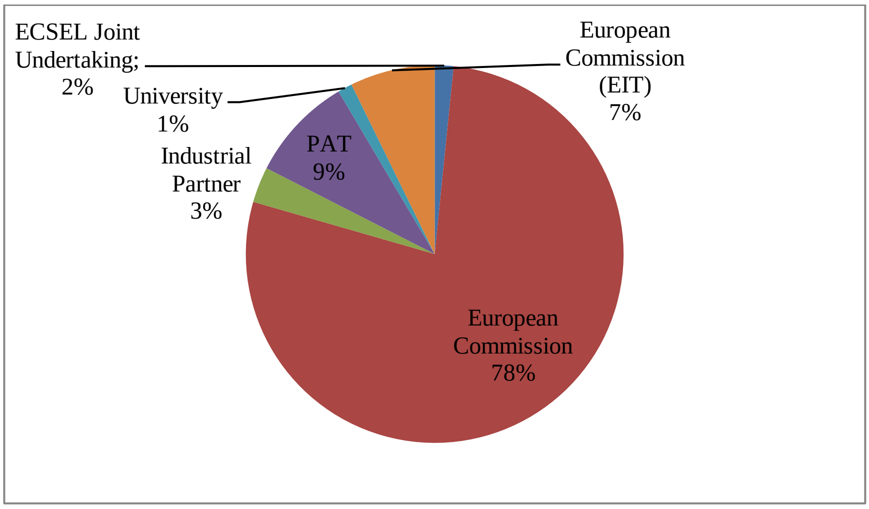
Source: https://ict.fbk.eu/

Figure 31: Distribution of the projects' revenues in FBK by technological area[200]



Source: author's elaboration

Figure 32: Distribution of the projects' revenues in FBK by counterpart[201]



Source: author's elaboration

Starting from 2017, the activities of the RL for the HII are focused on the following strategic objectives (Budget, 2017):

- Safety and Security (safe and highly reliable systems); specifically, the line of research on Adaptive, Reliable and Secure Systems[202] (ARSS) has competences in the field of software engineering, embedded systems and distributed adaptive systems. The main objective for 2017 is to improve the integration of

[200] The graph takes into account the overall projects between 1st January 2010 and the 31st December 2016, with total revenues for the foundation equal or higher than 250.000 Euro. This criterion was suggested to be significant during an interview with a scientific researcher.
[201] The graph takes into account the overall projects between 1st January 2010 and the 31st December 2016, with total revenues for the foundation equal or higher than 250.000 Euro. This criterion was suggested to be significant during an interview with a scientific researcher.
[202] ARSS includes the following research units: Embedded Systems (ES), Distributed Adaptive Systems (DAS), Intelligent Interfaces and Interaction (I3), Security & Trust (S&T), Software Engineering (SE), Energy Efficient Embedded Digital Architectures (E3DA) and ICT4G.

cyber security and safety systems in industrial systems; this RL will be developed in close cooperation with the research line related to Complex Data Analytics for the analysis of data generated by industrial plants. These objectives will be realized through collaborations with enterprises which are already developing projects in the direction of the 'Industry 4.0', like 'Boeing', 'Saipem' and 'British Telecom'. Given the success of the Co-Innovation Lab with Poste Italiane[203] on the issue of cybersecurity, they began a partnership with Fiat Chrysler Automotive[204] (FCA) for automatic driving cars and on cybersecurity with the Poligraphy of the State. Locally, they have in programme to create an ICT infrastructure for the development, validation and simulation of the Polo Meccatronica, the common infrastructure for the co-innovation lab.

- Data Science for Wellbeing; the competences of the line of research on Complex Data Analytics, Big Data, predictive models, analyses of the purchasing behaviour of mobile devises and monitoring of environmental data, are finalized to position FBK as one of the leading international centres favouring social well-being and global challenges, as health, the conservation of the environment, immigration, the problem of unemployment and criminality. This objective will be reached through the acquisition, on one hand, of advanced competencies in the field of automatic and deep learning techniques and, on the other hand, through partnerships with players in the insurance, banking, telecommunications and utilities sectors. A key role is played by the Co-innovation Lab, developed through an agreement signed in September 2016 with the Massachusetts Institute of Technology on Big Data Analytics for Human Dynamics Observatories. Complex Data Analytics are intended to be systems able to analyze big data and transform the restless streams of data in value, knowledge and decision capability[205].

  There are three main research units being part of this line of research: Predictive Models for Biomedicine and Environment (MPBA), dealing with mathematical models and ICT platforms for high dimensional data; Neuroinformatics Laboratory (NILAB), an interdisciplinary research in cognitive neuroscience and Digital Commons Lab (DCL), which has the aim to study, support, popularize, and innovate the world of digital commons. The RL on Complex Data Analytics includes competencies in methodologies of predictive analysis (data analytics), mathematical models and network analysis, machine learning and it plays an important role for the ability to build information technology

[203] The unit 'Security and Trust' has contributed to the creation of a co-innovation lab with Poste Italiane, on Cyber security, located inside FBK. In the lab, they work on monitoring and certifying the mobile applications for the management of the digital identity. The activities in the lab led to significant improvements from the point of view of the safety of the Digital Identity Public Service (SPID), recognized also from the Agency for Digital Italy (AgID). Therefore, Poste Italiane and AgID signed a Memorandum of Understanding between Poste Italiane and AgID in which the co-innovation lab with FBK has been identified to implement part of the security assessment activities of the SPID service.

[204] The Fiat Chrysler Automotive Research Centre is located inside FBK.

[205] Concrete examples are represented by the development of models able to predict situations of high criminality, to infer the risks for mental and physical health of specific behaviors and define which characteristics make a territory more or less cohesive and resilient to economic crisis. The ability to contribute to these international challenges is proved by the recent results achieved by the unit, the European project Esecurity, the collaboration with Telefonica and World Bank, the development of one of the first models for preventing the Zika or Ebola virus in Africa. Moreover, this line of research achieved interesting results in the field of clinical research, in particular with the pediatric hospital of research 'Bambino Gesù' of Rome, of which FBK has been a strategic partner for clinical analytics.

experimental platforms and other complex multi-disciplinary projects[206]. Moreover, it follows the enhancement of public open data supporting the scientific reproducibility of the new actions for the sharing of personal data[207]. In this field of research, important projects with many companies have been developed by the Energy Efficient Embedded Digital Architectures (E3DA) unit[208].

- Content and Interaction**;** the competences of the line of research of cognitive computing (language, artificial vision, analysis of the audio signal, semantic and knowledge management) are functional to two main objectives: the understanding of the mass media contents and conversational agents. The project *"Understanding Multimedia Content"* has the purpose to develop an innovative technology integrating learning and deductive models, able to operate on images, videos, texts and speaking. In 2017, a new transversal project will be launched where language techniques, semantic and audio recognition will be useful to face the challenge of conversational agents[209]. In order to reach these objectives, they are evaluating the possibility to launch co-innovation labs with enterprises and R&D labs with a highly market oriented approach, creating systems supporting and replacing social media manager in the generation of contents for advertising campaigns and in the direct conversation between the brand and consumers (Budget, 2017).
- Open Public/Private Ecosystem; a best practice project is 'TreC' (Figure 33), the Citizen Health Record, used by 60.000 citizens, which resulted from a successful PPP between the Healthcare Department of the Province, the medical company (Azienda Sanitaria) and FBK. Starting from January 2017, the new Competence Centre, "Trentino Salute 4.0" is operating as main cohesion policy tool for a proper integration between the needs of the health care system for innovative services and the opportunities offered by the research on new digital technologies. This project has been developed starting from 2008, and thanks to the consistent funds and efficient management of the Province of Trento. The head the e-health unit stated clearly that:

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206 Epidemiology, frontier genomic research, neuroscience, environmental monitoring and study of the human behaviour in socio-technical systems are the main areas of scientific impact of this line of research, and the technology for deep learning is the particular frontier of complex data.

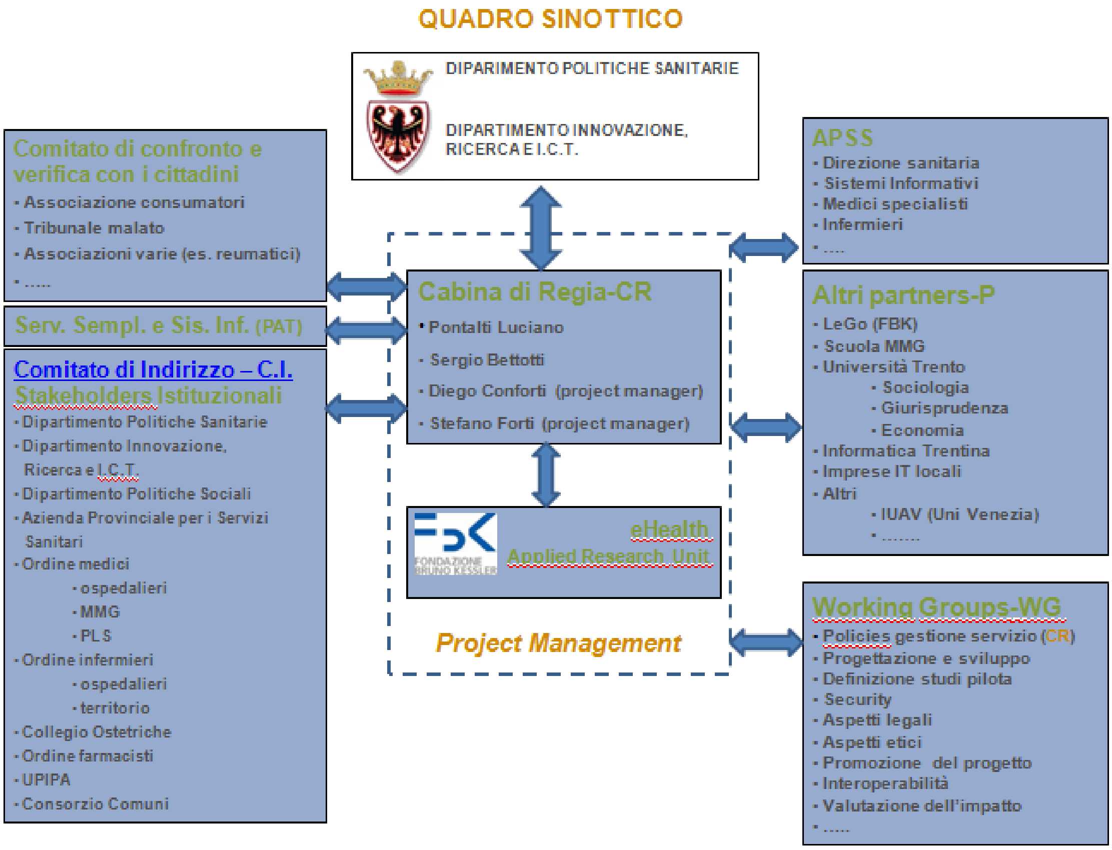
207 Another interesting project emerged in the agrifood sector, is the Fruitipy prototype, which integrates predictive algorithms of deep learning with a low cost spectrometer of small dimension measuring the state of maturation and health of plants. In this project, it is enhanced the capacity to manage big environmental data, sharing an IOT platform for wearable sensors. Another important contribution is the application of Sport Analytics for ski security; in cooperation with entrepreneurs of the sector, SicurSkiWeb will be extended to the overall Trentino System. There are two successful projects of 2016: the collaboration with a big pharmaceutical enterprise (UNIFARM) and a project with EIT Digital Reply with innovative services on dashboard for data analytics and predictive analysis, exploring some important applications in the context of e-Commerce and insurance. The collaboration with Nanyang Technological University in Singapore has been developed to exploit the potentialities of the FBK platform of data analytics for data with physiological sensors and the development of new options in the sector of intelligent design with the start-up MotoriaLab, a start-up providing technological solutions, high-resolution services and data for outdoor sports, based on wellness and safety and high top national enterprises in the sector of techno-sportive clothing.

208 For example, they supported 'Salewa', a company producing mountain clothing and equipments, embedding wireless communication and sensing capabilities to improve user safety and enhance the sport experience; they cooperated also with CoRehab Srl, a start-up in the medical sector, helping the company to keep their products at the edge of motor rehabilitation technologies. Specifically, their task is to help companies facing the challenges of an uncontrolled environment and of possible non technology-expert users.

209 In the context of the increasing request on the market of 'chatbots', social robots and systems able to dialogue with people, the challenge is to build systems able to have a conversation, trying to overcome the fix schemes limiting their real use, for example by taking into account the history of the dialogue.

"The main keys for the success of TreC have been, on one hand, the successful interaction between the policy maker, the research centre and the local medical enterprise and, on the other hand, the strategic view of the public actor, which believed very much in this project from the beginning and supported it with large financial aids; the involvement of each actor has been essential for the success of the partnership; similar past experiments have failed due to the lack of just one of the players involved" (Head of the E-health unit, FBK).

Figure 33: "TreC" the Public-Private Partnership for the citizens' digital medical record



Source: FORUM PA (2009)

Moreover, the idea is to develop a comprehensive record of the citizen, not just limited to monitoring the aspects linked to health care, but to every dimension of the life of the citizen, from mobility, to cultural services. The purpose is to elevate the digitalization of the enterprises, the Public Administration, building an open source and shared platform for interoperability between data and services in different domains, which are usually non interoperable projects and are realized separately. Interoperability is considered the first step towards the full exploitation of Big Data analytics.

"This project will be the starting point for the development of a shared inter-operable platform, a Citizen Record, that will make it possible to monitor data related to health, school, labour and culture, which are typically isolated in different silos, and in different domains" (Head of the ICT Centre, FBK).

In order to reach this objective, a Co-innovation Lab has been developed with Dedagroup, which is one of the Italian most influential IT players. The co-innovation Lab between FBK and Dedagroup, on Big Data Analytics, is aimed at developing new standards for the improvement of interoperability of data and services (open data, open services) and for realizing a new generation of digital applications.

Alessandro Profumo, the President of FBK stated that:

"*The partnership between Dedagroup and FBK signs the beginning of a new 'open innovation model' era on the territory of Trentino. FBK will provide to Dedagroup a co-working environment where the researchers of the foundation and of the enterprises will exchange knowledge, experiences and laboratories. FBK will share the results and competences in research and innovation and Dedagroup will give its project management and engineering support. The goal is to create a synergy between Dedagroup and FBK able to support the development of new and competitive products for the digitalization of institutions and enterprises. A new history of Trentino, the Italian Silicon Valley, has begun" (President of FBK).*

Finally, the EIT Digital node is aligned with the RL of the ICT centre. The action line of 'Digital cities' is completely aligned with the two main activities of the ICT centre "sustainable mobility" and "open services", and in particular with the strategic objective to create an "open public/private Ecosystem"; the action line "Smart Retail" is aligned to the HII on Future Media, with the RL on Complex Data Analytics and on Data Science for Good. Finally, the action line "Digital Industry", is aligned with the ARSS and in particular with the strategic objective on "Safety and Security".

As a result of the strong involvement of FBK in the European network of high level research institutes, the foundation is preparing to build a position in the development of quantum technologies, in a synergy between CMM, ICT, ECT, LISC, the University of Trento and the CNR. The 17th May 2016, the European Commission announced the launch of the new Flagship on Quantum Technologies for a total amount of 1 billion of Euro.

A project for local development: Open Prom Facility Lab

In line with the spirit of the European PPPs described in the previous chapters, the Open Prom Facility Lab (Figure 34 and Figure 35), a PPP between Trentino Sviluppo, FBK, University of Trento and Confindustria Trento, aims at combining the different instances coming from the enterprises, the education system and the policy spheres.

"The industrial world is very much conscious about the importance of concepts such as 'Mechatronics', 'Ubiquitous Computing' and 'Internet of Things', that, within 3 or 4 years they will be diffused in the European factories. These systems will be able to realize mechanical manufacturing with high added value and high performances, thanks to the integration of 'smart' control systems in mechanical and precision systems; in order to do so, it will be necessary in the short term to fill up the gap of the lack of qualified human capital with adequate technical and professional skills" (Prom facility Lab, 2016).

The Prom Facility Lab is thought to be an answer to the needs of the enterprises to adopt advanced technologies for smart manufacturing and qualified human resources to manage these transformations, thanks to the close cooperation between FBK, sharing its competences in a synergic relation between the ICT and the CMM centres, the technical institutes, ITT Marconi, CFP Veronesi[210], offering courses in mechanics, electronics, information technologies and the University of Trento, supporting Polo Meccatronica with knowledge sharing activities.

There are some relevant competences that FBK will share, covering the entire value chain: methodological support and instrument for the design of systems, from the user interface to the hardware and software architecture, to the modelling of behaviours; human-machine interaction technologies, as graphic interface projects able to control machines with a user centred approach; the design of ICT tools facilitating the training of employees; new methodologies of human machine interaction like smart interface, smart systems and wearables; smart sensors for industrial automation, thanks to the distinctive capacity to design and produce series production of electronic sensors and MEMS; cyber security systems, able to make systems vulnerable and resilient with respect to cyber attacks; reliable automatic instruments for the analysis and monitoring of existent workflows; tribological covering for the mechanical components to improve the performance and durability and the minimization of the energy consumptions in an industrial automated system; 3D printing, in which the foundation is involved in two main lines of research: the application of 3D printing to metallic artefacts; the Multifunctional Additive Manufacturing, multifunctional production of artefacts through embedded electronic components, realized in a unique solution.

The project gives great importance to the need to take into account professional institutes as strategic players of the innovation system which need to adapt the competences to the new technological challenges. In fact, the main pillar of this model is the so called "Knowledge Triangle", based on a close integration between the government, the academy and the industry; the objective is to create a T-shaped student having a deep competence in a specific discipline (that represents the vertical axis of the model), which, at the same time, is able to communicate with other knowledge domains (the horizontal axis of the model). A multidisciplinary approach, measured not in terms of 'quantity' of notions to absorb, but in terms of ability to communicate with different fields of specializations; the original contribution of this approach aims at creating a synergy between the research centres offering support to the training of students though the acquisition of new competencies, that can attract innovative enterprises. The creation of new competencies can make the difference both for the local enterprises and for those enterprises coming from outside.

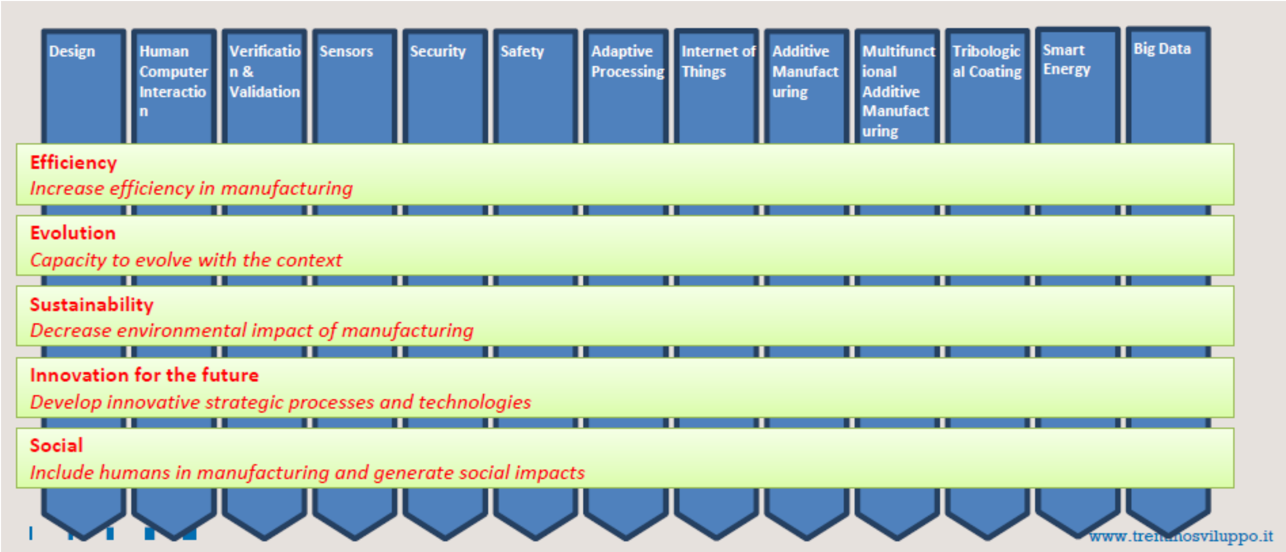
"It is not just a matter of integrating electronic control or software control to some mechanical parts, but to think in a new way to the final module. It is not a matter of 'things to do', but the 'way they are done' (...). In the middle term, the great potential of this technology will be its interaction with IOT technologies: embedding electronic systems (sensors, transmitters, sources of energy, antenna) inside the artefact

[210] CFP Veronesi has recently promoted a new curriculum in collaboration with the Fashion Institute Canossa focused on the creation of the so called "Digital Manufacturing Designer" in a multidisciplinary approach combining mechanical, electronic and ICT competences with design modelling.

produced in 3D will open the way to the use of a technology with a huge potential for Cyber Manufacturing" (Prom Facility Lab, 2016).

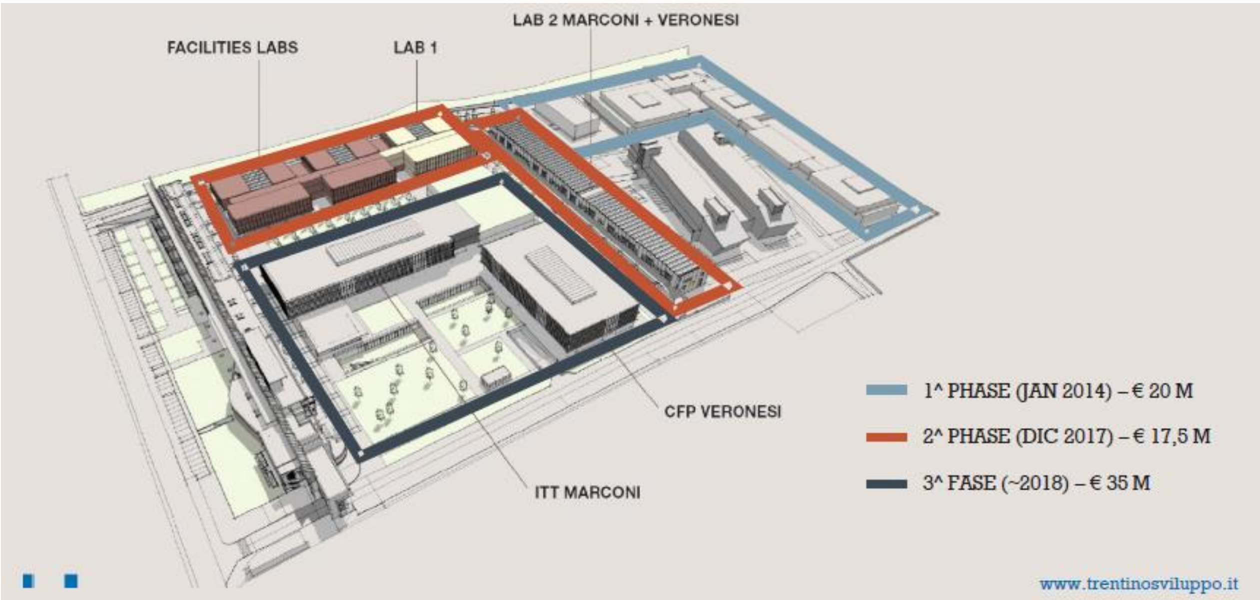
"The real source of competitive advantage will be hiding the software inside the hardware: a new way of doing manufacturing, the only chance to beat the competition of low cost countries (Technology Intelligence and Transfer, CMM Centre, FBK).

Figure 34: Competences of the Mechatronics Hub for the 5 goals of manufacturing challenge in Horizon 2020



Source: Gregori (2016)

Figure 35: Polo Meccatronica Master plan



Source: Gregori (2016)

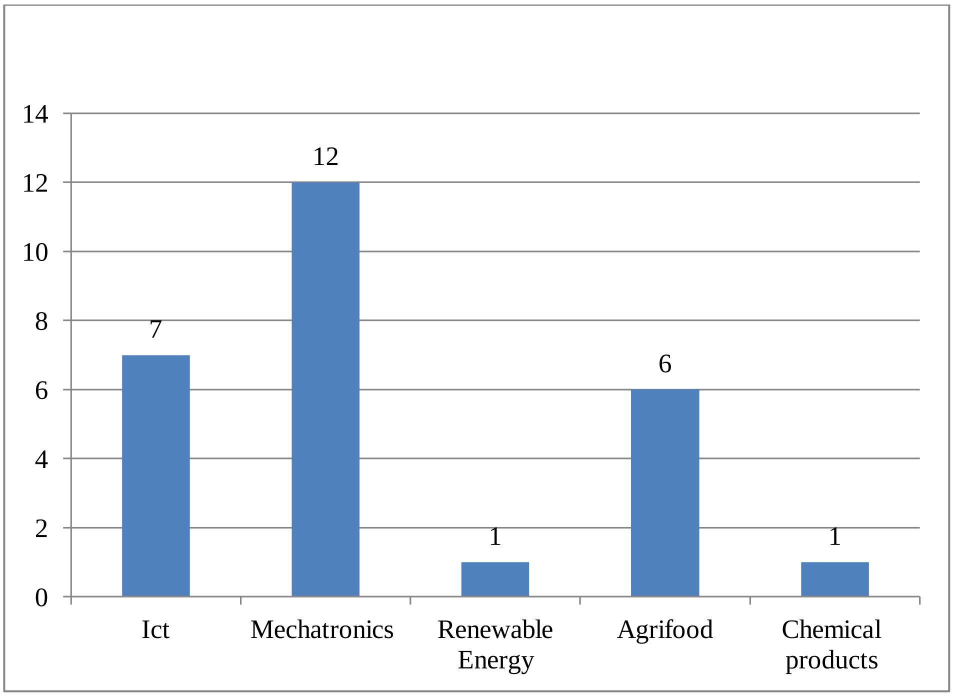
4.2.3. Research on the field

4.2.3.1. The sample and the questionnaire

The sample

I have adopted a sample of 27 firms operating in four strategic areas identified by the Province according to the RIS3. Figure 36 shows the distribution of the sample of firms interviewed by sector; as can be seen 12 operates in mechatronics[211], 7 in ICT, 6 in agrifood, 1 in renewable energy services and 1 in the manufacturing of chemical products.

Figure 36: Distribution of the sample of firms interviewed by sector



Source: author's elaboration

Table 43 and Figure 37 show the distribution of the sample by NACE code 4-digit and technological intensity, according to the Eurostat definition. Figure 37 shows that the 48% of the total sample operates in KIS sectors, followed by the 19% operating in the high-tech manufacturing sector, the 11% in low-tech manufacturing sector, the 7% in less KIS and the 15% in other sectors. Almost the 70% of the total sample operates in high-tech manufacturing and service sectors, which are particularly dynamic in terms of innovative activities, as emerged in Chapter Three.

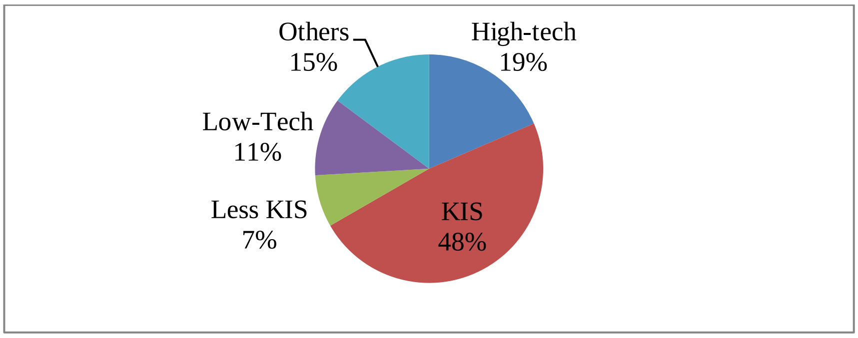
[211] The term 'mechatronics' (PAT, 2016) indicates a multidisciplinary field of science that includes a combination of mechanical engineering, electronics, computer engineering, telecommunications engineering, systems engineering and control engineering, aimed at improving the functionality of a techno-productive system.

Table 43: Distribution of the sample of firms interviewed by NACE code

Number of firms	NACE 4-digit description
1	2822 - Manufacture of lifting and handling equipment
2	6202 - Computer consultancy activities
7	6201 - Computer programming activities
1	4321 - Electrical installation
1	0121 - Growing of grapes
1	3320 - Installation of industrial machinery and equipment
1	2651 - Manufacture of instruments and appliances for measuring, testing and navigation
1	2060 - Manufacture of man-made fibre
1	2670 - Manufacture of optical instruments and photographic equipment
1	2896 - Manufacture of plastics and rubber machinery
2	1102 - Manufacture of wine from grape
1	6209 - Other information technology and computer service activities
3	7219 - Other research and experimental development on natural sciences and engineering
1	3511 - Production of electricity
1	4721 - Retail sale of fruit and vegetables in specialised stores
1	0161 - Support activities for crop production
1	4634 - Wholesale of beverages

Source: author's elaboration

Figure 37: Distribution of the sample of firms interviewed by technological intensity

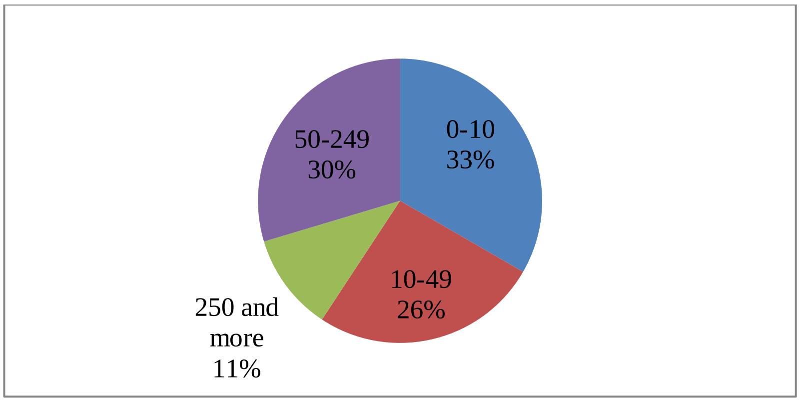


Source: author's elaboration

Figure 38 shows the distribution of the sample by size; as can be seen, the sample is distributed quite homogenously between firms with different classes of employees: 33% have a class of employees between 0 and 10; 26% between 10 and 49; 30% between 50 and 249 and 11% with 250 or more employees.

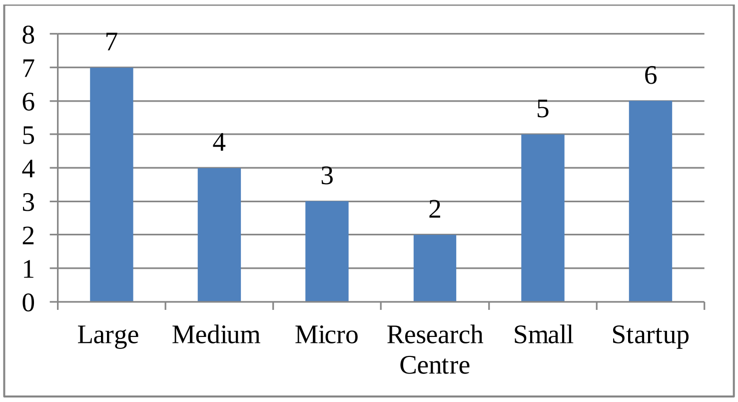
According to the rules of the European Union[212], Figure 39 shows the distribution of the sample by typology of enterprise; there are 7 large enterprises, 6 start-ups, 5 small enterprises, 4 medium enterprises, 3 micro enterprises and 2 research centres.

Figure 38: Distribution of the sample of firms interviewed by class of employees



Source: author's elaboration

Figure 39: Distribution of the sample of firms interviewed by type of enterprise

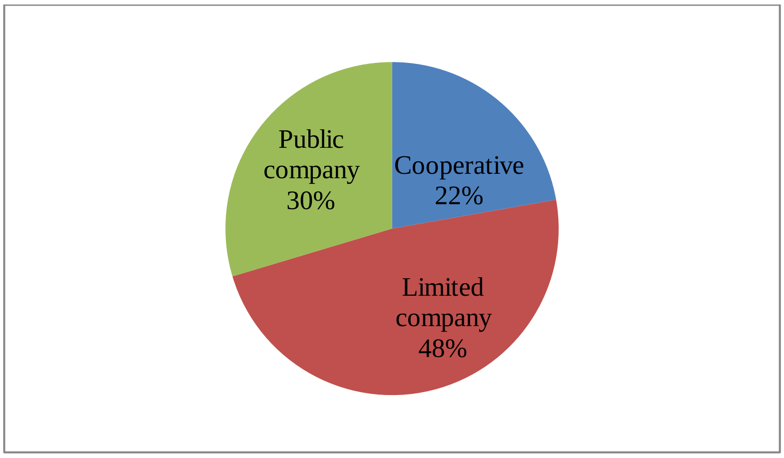


Source: author's elaboration

The distribution of the sample in terms of societal form is shown in Figure 40; there is a predominance of limited company (48%), followed by public companies (30%) and cooperatives (22%).

212 For further details, please see the report "Guida dell'utente alla definizione di PMI", European Commission (2015a).

Figure 40: Distribution of the sample of firms interviewed by societal form



Source: author's elaboration

The questionnaire

The details of the questionnaire are contained in Appendix 2, at the end of the Chapter. Generally, the main purpose of the interviews has been to understand the following aspects: the business strategic approach adopted by the company; the level of knowledge and adoption of the 'Industry 4.0' KETs[213]; the approach to innovation activities (the main cooperative players involved, the participation to public calls for innovation activities, the type and amount of public fund received). Table 44 summarizes the list of the managers interviewed, by sector.

Table 44: List of the representatives of the firms interviewed by sector

N°	**Sector**	**Function**
1	Agrifood	Production Responsible/oenologist
2	Agrifood	Technical Director
3	Agrifood	Technical Director
4	Agrifood	CEO
5	Agrifood	CEO
6	Agrifood	Marketing/Technical Director
7	Mechatronics	R&D manager
8	Mechatronics	Advanced Engineering Manager
9	Mechatronics	Digital Strategist
10	Mechatronics	CEO
11	Mechatronics	CEO

[213] The KETs of the 'Industry 4.0' paradigm have been described in Chapter Three. For the interviews I have adopted the definition of the Osservatorio Smart Manufacturing (2015).

12	Mechatronics	Quality & Environmental Management
13	Mechatronics	Chief R&D Officer
14	Mechatronics	Technical Manager
15	Mechatronics	CEO; Technical Director
16	Mechatronics	CEO
17	Mechatronics	Owner
18	Mechatronics	CEO
19	ICT	CEO
20	ICT	Director Technology & Innovation
21	ICT	Owner
22	ICT	CEO
23	ICT	CEO
24	ICT	CFO
25	ICT	CEO
26	Manufacturing of chemical products	CEO
27	Renewable Energy	Chief Operating Officer

Source: author's elaboration

The following sections analyze the results of the interviews by sector.

4.2.3.2. Results of the interviews: Agrifood, Mechatronics and ICT

Table 49 at the end of the paragraph summarizes the main results of the interviews along two main dimensions: the level of adoption of the 'Industry 4.0' KETs, the approach to innovation, focusing on the development of formal collaborative agreements with the other partners, in particular with Universities and public research centres and the main funding tools adopted.

Agrifood

Agrifood is a strategic sector for Trentino. A great variety of productive sectors are included in this category (PAT, 2016): the primary sector, mainly related to crop and animal production, forestry, fishing and aquaculture; the manufacturing sector, which includes manufacturing of food products, beverages and packaging; the service sector, related to accommodation and food service activities.

The agrifood sector contributes for a relevant share of the total added value in Trento, equal to about 780 million of Euro, about the 6% of the total value added at basic prices (taking into account the primary sector, the industry and the service sector) and has a total number of enterprises subscribed to the Chamber of Commerce, equal to 16.500 units, about the 40% of the total number of enterprises subscribed in the primary sector, the industry and the service sector (PAT, 2016).

The sector is characterized by the prevalence of cooperatives and organizations of producers, representing most part of the production of the Province. In this sector, the territory is supported by many research and innovation centres: FEM, CNR Department of "Earth System Science and Technology for the Environment" (IBAF); University of Trento, with the *Centre for Computational and Systems Biology* (COSBI); Master courses promoted by the University of Trento, like the course in Viticulture and oenology, together with the range of courses in the agrifood sector for entrepreneurs and farmers. Also in the international network, the Province plays an active role thanks to the participation to the European PPPs “Sustainability and Productivity in Agriculture” and “Food4future”.

In this sector, the survey took into account 6 enterprises: 1 small firm specialized in the production of wine and extra virgin olive oil, 1 medium firm specialized in the production of wine, 3 large firms specialized in the manufacturing of wine from grape (1 of which family owned and managed) and 1 large firm specialized in the production and sale of small fruits.

Table 45 here below shows the share of firms by NACE code, type, legal form, technological intensity and type of management.

Table 45: Share of the firms interviewed in the agrifood sector by NACE code, type, legal form, technological intensity and type of management

NACE Code description	Type of firm	Legal Form	Tech-Intensity	Family-owned and managed
0121-Growing of grapes	1 Small	Cooperative	Others	No
0161-Support activities for crop production	1 Medium	Cooperative	Others	No
1102-Manufacture of wine from grape	2 Large	Public companies	Low-Tech	1 Yes, 1 No
4634-Wholesale of beverages	1 Large	Cooperative	Less KIS	No
4721-Retail sale of fruit and vegetables in specialised stores	1 Large	Cooperative	Less KIS	No

Source: author’s elaboration

The approach to Industry 4.0

First of all, each of the firms interviewed, regardless from the size, has adopted digital platforms for the ‘smart’ management of vineyards and fields. As shown in Table 45, most of the firms interviewed in the agrifood sector (4 out of 6) are cooperatives, a quite common legal form in Trento, composed by a high number of members to monitor and coordinate; the good communication between them and the need to integrate information coming from the fragmented vineyards and fields distributed all of over the region have always been relevant issues for the local famers. The adoption of highly integrated platforms makes it possible for these to increase the efficiency in farming activities, thanks to some important operations: manage efficiently the big amount of data deriving from the cultivated lands (owners info, land register, transfers, soil and microclimate); combine the territorial and environmental data with financial and economic analysis concerning productivity, in order to evaluate and improve the economic impact of the vineyard management; support agronomists with predictive analyses concerning the best moment to implement the treatments, on the basis of time, of the product used during the last treatment, of the characteristics of the vineyard and concerning past and future weather trends, in order to prevent possible diseases.

These systems are proper strategic planning tools supporting agronomist and growers with real time assistance through some important activities: geo-reference the vineyards, extract key information concerning territories, including bio-climate indexes, pre-harvest information for the calculation of maturation curves; monitor the phenological phases directly through cloud-supported smart phones and tablet applications; have automatic access to the data concerning the production process and of the laboratory analysis, in order to analyze the relationship between the management of the vineyards and fields and economic and financial analyses. 5 out of 6 enterprises interviewed developed these integrated platforms thanks to the partnership between FEM, FBK and Mpa solutions, a software enterprise developed as a spinoff of FBK, in particular from the MPBA unit of the ICT centre, specialized in predictive models on complex spatio-temporal patterns[214].

"Thanks to the extremely high level of precision of these tools, we can increase not only the efficiency of farming activities but also the quality of our products, thanks to a proper understanding of which can be the best product coming from a land according to its specific characteristics; this was impossible before" (Oenologist, Wine Company).

A second interesting project highlighting the potentialities of advanced information systems for enterprises operating in the agrifood sector is 'Fruitipy'[215]; this project is based on the use of sensor technologies as measuring methods for evaluating fruits' maturity level; it has been developed by a group of researchers in FBK, in the context of Web Valley[216] and involves two of the large enterprises interviewed. The project is the result of an important intuition: the increasing quality expectations and growing awareness of consumers in recent years and the inability of common measurement methods to meet the quality standards required; the need to improve measurements' precision reducing wastes suggested the idea to use imaging and spectroscopy as possible measurement devices[217].

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[214] The enterprise is specialized in the application and development of innovative tools for the enhancement of geo-referenced data, for their use in the decisional process, providing support with highly innovative solutions to the needs of the private enterprises and of the Public Administration (PA).

[215] For detailed information, see: https://mpbalab.fbk.eu/fruitipy-parameter-identification-in-agrofood/

[216] Web Valley is the FBK summer school for 17-18 years old students, with the aim to create an interdisciplinary research environment for the exploration of new web-based services for managing and sharing data in the ecological, environmental and social interest.

[217] Currently, a prototype by a group of students of the 16th edition of Web Valley has been developed, formed by a spectrometer based on a minicomputer communicating with a smart phone that is able to detect the level of chemical composition and therefore the level of maturity of fruits.

This project has a particular potential for wine and small fruits production enterprises, for which the identification of the precise level of fruit's maturity is crucial for the success of the final product. It improves the efficiency of production process, reducing wastes in terms of time, product, and increasing the quality of the measurement precision[218]. This project is an example of 'precision farming' methodology, able to support farmers in the constant need to face fast changing conditions throughout the growing season and the high heterogeneity of the territories to be cultivated.

"This prototype has the potential to have a great success on the market in 3 or 4 years time[219] (Head of the MPBA unit, FBK)".

The level of knowledge and adoption of the other "4.0 KETs" increases with the size of the firm. RFID technologies are mainly used by the four large enterprises, basically for monitoring employee's entry and exits and just in one case to monitor the entrance of fruit to be processed, while QR code are mainly adopted for marketing purposes; none of the companies interviewed adopted Supply Chain Management software monitoring the products' entire life cycle; each of the four large enterprises use an Enterprise Resource Planning (ERP) software, but just one of them has recently adopted a Warehouse Management System (WMS) for the management of daily planning, organizing, staffing, directing, and controlling the available resources in and around the warehouse; one of the large enterprises stated to be willing to introduce a Business Intelligence (BI) Software to improve predictive analysis for management purposes, while the SMEs use basic management software like Excel. Sensor systems are fully adopted by each of the enterprises to monitor environmental processes (weather stations...). Concerning the level of automation[220], none of them has adopted advanced automation robotics, drones[221], advanced human machine interaction devices, as wearables (smart gloves, smart glasses), or 3D printings. Only the four large enterprises taken into account has an ICT specialist, while the SMEs are not sufficiently structured to have an internal ICT manager; only two out of four of the large enterprises organize courses for improving the ICT competences for the employees both with and without ICT skills.

In general, the adoption of advanced automated technologies is not perceived in contradiction to the need to preserve the authenticity of local production, but instead as a chance to replicate on a larger scale the high quality level of their production; for example, the CEO of one of the wine companies interviewed stated that:

"The cellar of our company has been built in order to be able to replicate the high quality of our production on a large scale; this is the interesting challenge of this new technological paradigm: to be able to combine the 'high quality' with the 'large quantity'" (CEO, medium wine company).

[218] The device has been realized by a group of students between 17-18 years old, in collaboration with Cesare Furlanello, the head of the MPBA unit of the ICT centre in FBK, thanks to the use of a 3D printer; they also created the interface for smart phone and developed complex algorithms of artificial intelligence for the maturity classification.

[219] For further info, see the link: http://corriereinnovazione.corriere.it/2016/07/26/fruitipy-strumento-che-rivela-se-frutta-matura-574883e0-535c-11e6-91a0-d48edbbc23e8.shtml

[220] One of them has implemented the first fully automated cellar in Italy.

[221] One of the large wine production enterprises adopted drones to realize a video documenting the different phases of the harvest, and the production process in wine cellars for an importer, watched though smart glasses. The same enterprise has a supplier providing prototypes of new lines of bottles realized through 3D printing.

This position is, however, not always supported by the old generation oenologists and growers who have some doubts over the possibility to maintain the high quality level of production in a context of advanced automation.

"Technology and advanced automation are not our primary interest; we have decided to adopt a strategy based on high quality and we are afraid that adopting a highly advanced automation process would compromise the uniqueness of our products, giving in to a standardized product" (Oenologist, medium wine company).

Approach to collaborative innovation: main players involved in the innovation processes and funding tools

In general, the players more involved in innovative projects for the development of new products are clients from the private sector, while those involved in innovative projects for the improvement of the production processes are Universities and research centres. The attitude towards innovation does not depend much on the size of the firm, but on the level of 'open-mindedness' of the entrepreneurs and of the operating management. The small firm interviewed, for example, has shown a higher attitude towards innovative projects, in comparison to the medium firm, having developed projects with Universities and research centres for the improvement of production processes[222].

Each enterprise interviewed has shown a particular attention towards issues related to environmental sustainability (use of clean water, the adoption of photovoltaic sources of energy, the use of environmental friendly fertilization, biological lines of production...). Whereas private research centres are considered dynamic players supporting firms' innovative activities, each of them suggested the need to improve the level of proactiveness of Universities, in particular concerning issues related to environmental sustainability. The large majority of them raised difficulties in communication with Universities, which are too theoretical and abstract and suggested the need to focus on research lines which are closer to the needs of the local enterprises and which they are not able to solve on their own[223].

Public entities, like associations and consortiums are considered merely bureaucratic entities, whose efficiency, utility and degree of professionalism need to be improved[224].

As for the use of public funds, the main financial tool adopted to finance the innovation activities is the Law 6/99: each enterprise stated to have benefited of these funds; two out of the four large firms taken into account have participated to the OCM public funds envisaged by the Ministry on behalf of the European Union. Most of the enterprises stated that public funds are an important stimulus but not crucial conditions

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[222] This company is developing a strategic project with the University of Perugia for the development of a high technological machine able to extract polyphenols from the olives' vegetation water.
[223] For example, the small enterprise interviewed complained about the lack of projects pursued at national level, aimed at solving the problem of diseases caused by olive flies, which represents a major threat for entrepreneurial activities in the agrifood sector. An exception to this general feeling is represented by one of the large enterprises interviewed, which is positively involved in different innovation projects with Universities.
[224] Concerning other strategic partners for innovation, one of the large wine enterprises mentioned the relationship with a new German partner as a strategic actor for new innovation projects.

for investing in innovation activities: they would have developed those projects also without the financial aids.

Concerning the main strengths and weaknesses of Trento's innovation system, there is a general convergence of opinions.

Each of the firms interviewed are generally satisfied about the overall functioning of the innovation system; the possibility to have access to high level and proactive research institutes like FBK and FEM is considered an important strength of the local system; they benefit also of the indirect contribution of these research centres, thanks to spinoff companies that play an important 'systemic' function on the territory.

Moreover, the presence of advanced telecommunication infrastructures is considered an important strength, making it possible for the enterprises located in disadvantaged areas to be well connected thanks to the presence of fibre optics all over the territory. Also the geographical position is considered an important aspect for the general innovativeness of the territory thanks to the possibility to have an easy access to central European business networks. Some main weaknesses are highlighted: the high level of bureaucracy of public institutions, the need to improve the level of professionalism of public entities and the need for Universities to be more proactive on the territory towards issues of public interest.

Mechatronics

The term 'mechatronics' (PAT, 2016) indicates a multidisciplinary field of science that includes a combination of mechanical engineering, electronics, computer engineering, telecommunications engineering, systems engineering and control engineering, aimed at improving the functionality of a techno-productive system. As already mentioned, mechatronics is a particularly important sector in Trento: there are 300[225] enterprises operating in this sector, about the 7% of the total active enterprises operating in the industry. There is also a significant number of registered patents, a total of 50 patents, about the 50% of the total patents registered in Trento, and of innovative start-up in this sector (10, almost the 25% of the total), in the field of electronics, optic and electric devices.

The main players involved in the innovation processes in this area are the following: the Department of Physics and Engineering of the University of Trento; the CMM centre in FBK; "Istituto Nazionale di Fisica Nucleare"; CNR (in particular the unities specialized in micro-mechanics and micro-optics). As already mentioned, Trento plays a strategic role in the international network, participating to the European Innovation Partnership on Raw Materials.

The survey involved 12 enterprises: 5 located inside Polo Meccatronica, 1 located inside Progetto Manifattura, and 6 outside the Polo Meccatronica. Table 46 shows the distribution of the sample by 4-digit NACE code, type, legal form, technological intensity and type of management, and Table 47 shows the distribution by sector, size, belonging or not an innovation pole. The 6 enterprises inside Polo Meccatronica

[225] This value refers to a database of companies of the Chamber of Commerce, which, due to the lack of a precise NACE code related to 'mechatronics', matches the NACE codes related to mechanics, electronics and information technologies.

are composed of: 2 research centres of two large enterprises in, respectively, industrial automation and ICT, 3 start-ups (2 in ICT and 1 in R&D) and 1 small enterprise (in ICT). The other 6 enterprises not located inside the Polo Meccatronica are composed of: 3 small enterprises in industrial automation and 3 medium enterprises (1 in ICT and 2 in industrial automation).

Table 46: Share of the firms interviewed in mechatronics by NACE code, type, legal form, technological intensity and type of management

NACE Code description	Type of firm	Legal Form	Tech-Intensity	Family-owned and managed
2670-Manufacture of optical instruments and photographic equipment	Small	Limited Company	High-Tech	No
2651 - Manufacture of instruments and appliances for measuring, testing and navigation	Small	Limited Company	High-Tech	No
2822 - Manufacture of lifting and handling equipment	Medium	Limited Company	High-Tech	Yes
2896 - Manufacture of plastics and rubber machinery	Medium	Public Company	High-Tech	Yes
4321 - Electrical installation	Small	Limited Company	Others	No
6201 - Computer programming activities	1 research centre + 1 medium + 1 small + 2 start-ups	4 Limited Companies +1 Public Company	KIS	No
7219 - Other research and experimental development on natural sciences and engineering	1 research centre + 1 start-up	2 Limited Companies	KIS	No

Table 47: Distribution of the sample of firms interviewed in mechatronics by sector, size and belonging to technological hubs

Sector and size	Total	Technological hub
ICT	**4**	**3**
Medium	1	0
Small	1	1
Start-up	2	2
Industrial automation	**5**	**0**
Medium	2	0
Small	3	0
R&D	**3**	**3**
Research Centre	2	2
Start-up	1	1
Total	**12**	**6**

Source: author's elaboration

Inside the hub

The approach to Industry 4.0

Polo Meccatronica presents a high concentration of high-tech enterprises, mainly research centres of large enterprises, start-ups and incubators, very close to the 'Industry 4.0' paradigm. The first R&D unit interviewed is specialized in innovative solutions for the reduction of harmful emissions and alternative traction systems. It is based on a group of 18 engineers divided between Bologna and Rovereto headquarters; in 2012, the research centre chose to concentrate in Rovereto all the research activities related to the reduction of atmospheric pollution[226]. Recently, they were committed by the Ministry of the Environment to realize an electrical bicycle able to measure harmful emissions in the atmosphere; the electronics, the batteries and the environmental sensors are concentrated in red shells that may be adapted to all kind of bikes, becoming 'electric' and may be controlled through an ad hoc application for smart phones containing RFID technologies for self-identification. Components' singe parts of final products are often realized through an outsourced 3D printer; for their specific type of activity, it is not convenient for them to have an in-house 3D printer: they always need updated technologies. They rely on external cloud computing services, which are more compatible to big data computation.

[226] The agreement with the Province implies that every research project developed benefits of the incentives envisaged by Law 6/99.

"This is an example of high-tech project in which electronics, mechanics and information systems are integrated in order to monitor real time data and information related to environmental pollution; all of our projects are based on a strict interrelation between these different knowledge domains and it could not be any other way (...) every company located inside Polo Meccatronica has scientific research as its core business; similar poles of innovation of this level are difficult to find, also in Northern Italy. What makes the difference is having a long-term strategic business view, which considers knowledge and skills as priorities. I think that Trento's potential is to become an innovation centre for high-tech companies' R&D departments" (R&D manager, R&D unit, Polo Meccatronica).

The second R&D unit interviewed belongs to a worldwide leader in the design and production of traction systems for big industrial machines; on behalf of the American head office, the company leads from Trento the division of "Heavy Vehicles Technologies & Systems" with headquarters in Como, the productive units in Belgium, Hungary and in India; since 2015, the R&D unit specialized in advanced systems of traction for off road vehicle is located inside Polo Meccatronica. The unit is composed by a team of 10 engineers: mechanical, mechatronics, electronics and information technologies engineers, which facilitates cross-fertilization processes between different competences. They recently developed a highly innovative patent technology consisting of a fully integrated, connected vehicle that converts operating data from the drive train into actionable insights for enhancing productivity, improving operator and machine safety, and reducing total operating costs. This technology solution makes it possible to extract data from the vehicles, sent to a cloud supported platform, where complex algorithms are elaborated in order to understand how these vehicles work and improve their functionalities.

"It is an innovative platform developed in order to provide an answer to a specific request of our clients, asking for more integrated information to put on vehicles' board; the aim was to transform "passive" components of the transmission system into sources of intelligence and information: this technology has the potential to develop semi-automatic vehicles, that will be completely autonomous in the next future. (...) A technology which communicates with the final users on and off the vehicle, making it possible to share critical alarms and analysis on the display; (...) this is made possible thanks to automatic learning advanced algorithms which optimize productivity and efficiency, recognize learn and forecast the behaviour of the vehicle and of the operator" (Advanced Engineering Manager, R&D unit, Polo Meccatronica).

3D printings for prototyping have been often used during the last two years; they accelerate product development, with a consistent decrease in costs and with the possibility to perform immediately testing to clients. There are two main reasons leading the head office of the company to locate the R&D unit inside Polo Meccatronica: the conviction that innovation processes are benefited outside the vertical and hierarchical structure of large enterprises; the easy access to a cross-fertilization environment[227], with the possibility to benefit both of skilled human resources, thanks to Trento's excellent education system, and conspicuous financial aids.

"The possibility to have access to an 'open innovation' environment based on a real integration between educational institutes, business enterprises, Universities and research centres, makes this place second to none in Italy; in short time, we formed new business relationships with prototyping companies and we are positively looking at Prom Facility Lab which seems a precious opportunity in this direction" (Advanced Engineering Manager, R&D unit, Polo Meccatronica)

In Polo Meccatronica, I interviewed also three start-ups and the small enterprise, specialized in the KIS sector.

A first start-up is specialized in advanced e-learning platforms and software for managing multimedia contents for after sales service and web marketing solutions; this laboratory has developed wearables devices, like low cost smart glasses and smart watches to improve and facilitate workers' training activities; it has received recently an important international award, "Progetto CreatiFI", with the objective to spread the 'Internet of the Future' technologies in the context of the creative industries. CreatiFI has awarded the start-up as a 'European Digital Champion for the Creative Future Internet' with other 50 European companies. The main difficulty is dealing with enterprises which need to revise completely their internal organization in order to introduce disruptive technologies.

"Still, it is difficult to communicate the potential of our technologies to the Italian companies, which are burdened with heavy taxation and high bureaucracy and are not enough prepared to understand the opportunities lying behind these technologies; in my opinion, the '4.0 technologies' will not replace human work, but will support it (...). In this context, Trento's innovation system works far away better than other systems in Northern Italy, thanks to a good coordination between the local innovation agencies, like Trentino Sviluppo, which is very close to the interests of the enterprises (CEO, Small company)".

The second start-up interviewed is specialized in multi-touch and multi-user interactive tables for collaborative learning and work in team, according to the most advanced Human Computer Interaction criteria; it was born as an FBK spin-off, supported by the Seed Money Fund and co-financed by the Province; the main products developed by this company are cloud platforms for interactive tables, initially adopted in the context of the medical sector, which today have spread in different sectors (schools, museums,

[227] The centre mentioned the recent development of a business relationship with another company located inside the Polo, which would have not occurred elsewhere.

...); they prevalently work with clients in the public sector, while the private sector is more difficult to penetrate.

"The most critical aspect of our activity is represented by a lack of a 'commercial' attitude in our business approach; during the last years we have been working on 'complex' high-tech research projects, today we need to focus on how to translate in the best way our intuitions and ideas for the mass market; whereas public support in Trento allowed me to develop my business, the territory suffers of the lack of a proper industrial base, which limits possible business opportunities".

A third start-up, located in Progetto Manifattura, is one of the biggest Italian Fablabs; it is a high-tech fast prototyping laboratory provided with 3D printers, 3D laser scanners and advanced laser machines which can be used by any sort of enterprise to experiment and realize electronic prototypes and robotics. This centre is thought to be a place stimulating the interaction between different players (Universities, educational institutes, research centres, and enterprises) taking inspiration from the MIT Fabrication Laboratory in Boston.

"The idea is to replicate this project in Italy adapting it to the Italian way of doing business, based on manufacturing, creativity and relationships; Trento's environment is dynamic, but a different policy for start-ups should be implemented, supporting those that really have a potential and without adopting dispersed measures which stimulate fragmentation" (Owner, Fablab, Trento).

The small enterprise is specialized in Geographic Information Systems (GIS) innovative solutions in four main sectors: environment and territory, multi-utility and industry; smart city and smart building and health care.

"The idea is to translate the GIS technology into a knowledge tool for Human-Machine interaction; however, we have to understand how we can translate this project in the market; we have to wait for the market to express a specific need we can answer to (...). We have been one of the first companies to locate inside Polo Meccatronica; despite our efforts to be involved in partnerships with other players and to interact with others, we hardly find some convenience in this participation; what matters is not the logistic of locating many enterprises all together but the extent to which the different members are effectively able to communicate one with each other".

The company developed also an important PPP with the Province of Trento, the Consortium of Trentino's municipalities, FEM and FBK finalized at the forests' digitalization, applying "(...) the technologies used in the smart cities' experiments to the very different framework of woods and rural areas, which represent about the 80% of the regional land[228]”.

Innovation approach: main players involved in innovation and funding tools

Despite some isolated companies lacking of a clear ‘strategic vision’ for innovation, the primary reason attracting research centres, high-tech startups and enterprises to locate inside Polo Meccatronica and Progetto Manifattura is the possibility to have access to an environment which is rich of highly qualified players, research centres, Universities and educational institutes, factors often making the difference for companies seeking to innovate. Funding support (through Law 6/99 and European funds) is also an important motivation, but still less relevant. This position has been clearly expressed by R&D managers of units of large enterprises which have a clear business strategy from the beginning; for these enterprises, the main partners involved in innovation activities are Universities, Public Administration and clients from the private sector. These companies are generally satisfied by the efforts of the public actor.

The main critical aspects concerning the business activities are underlined by the start-ups and the small company interviewed: the difficulty of approaching the market due to a prevalent ‘research background’ of these companies; the technological barriers of most enterprises, which often need to revise completely their internal organization in order to introduce disruptive technologies; the lack of a solid local industrial system, which interact with; the need for more initiatives stimulating an effective interaction inside the hub; a myopia policy view favouring start-ups in the initial phases, but with little support in the crucial following phases of development, with the risk of fragmentation and waste of financial resources.

Outside the hub

Outside Polo Meccatronica, I took into account a sample of 6 enterprises: 2 medium high-tech enterprises, 1 medium KIS enterprises, 2 small high-tech enterprises and 1 small enterprise specialized in electrical installations.

The results of the interviews suggest the presence of two main categories of firms: one nucleus of three “traditional” enterprises and one nucleus of three “innovative” enterprises.

On one hand, the three “traditional” companies (2 medium high-techs and 1 small company) have a long history on the territory and operate in industrial automation: manufacturing of lifting and handling equipment, manufacture of plastics and rubber machinery and electrical installation. The 2 medium high-techs companies are family-owned and managed. They were subcontractors of important multinationals once

[228] This information is available at: http://www.polomeccatronica.it/en/news/smart-cities-smart-forests-trentino-leading-revolution

located in Trento, specialized in custom made solutions. On the other hand, the other three small enterprises (2 high-techs and 1 KIS), are characterized by a high propensity to innovate; two of them developed as spin-offs from FBK and specialized respectively in: the manufacture of silicon optoelectronic sensors, smart electronic systems and vision inspection technologies[229].

The approach to Industry 4.0

The three 'traditional' companies interviewed are characterized by a high ability to realize unique custom made projects for their clients and show a high latent potential to become key players in the 'Industry 4.0' debate.

"Born and developed thanks to the founder's invention during the Sixties, we built our competitive advantage on the ability to realize custom made solutions for our clients: we are like artisans in the mechanical engineering" (Quality & Environmental Management, High-Tech Company). "We are specialized in the construction of production lines for companies in the tyre industry; we are integrators of '4.0 technologies'" (Technical Director, High-tech Company).

However, the level of diffusion of '4.0' key technologies among these companies is relatively low.

Just one enterprise out of three uses RFID technologies to monitor and control the industrial production from the semi-finished to the final product, adopted a Supply Chain Management software, with a fully integrated monitoring system, advanced automation systems for production and use display touches to monitor the production process. Two of them use QR code technologies for maintenance purposes. None of them use cloud computing services, mainly for issues linked to security and the need to maintain adequate flexibility; working with clients who are often competitors implies a too high risk, suggesting the need to improve cyber security tools. None of them use 3D printers. Just one of them expressed the intention to introduce big data analytics software, underlining the need for adequate infrastructures able to support and deal with large amounts of data. Thanks to a partnership with a German partner, the small enterprise specialized in electrical installation developed an advanced MES software with a modular structure that enables vertical data integration, transparency, horizontal communication, real-time processing of machine and operating data. Just one of them has an ICT internal specialist and organizes training courses for employees with ICT competences and without ICT competences.

Some main difficulties are underlined by these companies in meeting the 'Industry 4.0' challenge.

First of all the lack of adequate support from the system: the only inputs for innovation processes in the '4.0 direction' come from their business network, mainly clients of the private sector and suppliers.

A second critical aspect is represented by the lack of a clear business strategy able to face transformation processes; it is the case of companies which developed thanks to the brilliant invention of the

[229] The third is a software engineering enterprise, which will be described in details in the section dedicated to the business case studies.

founder, which today face the risk of possible technological lock-in due to the inability to adapt to the changing environment, related to a family-owned resistant to change approach.

"The rapid advances in robotics do not represent a threat for us, because we think that human's intelligence is still superior to that of machines'; it is not easy to introduce innovations in the context of a family-owned company which is very tied to its tradition and long history on the territory" (Quality & Environmental Management, High-Tech Company)

Other issues underlined are the size and the lack of an adequate level of knowledge of local businesses, highlighted in particular by the small company.

"We started to explore the 'Industry 4.0' debate during 2013, when we became partner of a German company and finally participated to the realization of a highly advanced software for data integration. However, we had difficulties in promoting it because we feel that the market is not ready yet" (CEO, Company in electric installation).

The other three small enterprises interviewed are interesting cases of high-tech and KIS companies, two of which started to develop in the Nineties as spin-offs from FBK, CMM (unit of artificial intelligence)[230], specialized respectively in the manufacture of silicon optoelectronic sensors and smart electronic systems[231] and in vision inspection technologies for the bakery industry[232].

"*In the Nineties, spin-offs were not so often; we have been one of the first companies in Italy to risk in business activities because we were seeking to reduce the distance between 'scientific research' and the 'market'; we had the idea that Trento, thanks to the presence of high level research centres could have the potential to become like the Silicon Valley" (CEO, High-tech company).*

These companies have an attitude towards innovation which is highly dynamic, with a strict relationship with Universities and research centres. However, there are some main critical aspects underlined: first of all, the need to develop a 'market oriented attitude'; these are companies founded by scientific researchers who often lack of a business attitude.

"Innovation maybe a tomb for the company when market trends are not understood and requests are not satisfied" (Technical Manager, high-tech firm).

Another aspect underlined is the need for companies to adapt their internal skills to the fast changing technological environment, which is a crucial issue in the 'Industry 4.0' debate.

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[230] The third company is fully described in the section dedicated to the business case studies.
[231] These have possible applications in multiple sectors: the industrial sector, in particular in positioning sensors for robots and CNC machines; the design and production of intelligent electronic sensors for earth-moving spatial vehicles, farming and construction machines, aerospace, biomedical and environmental sectors, in which they developed microelectronic technologies for optical and optoelectronic sensors, also thanks to strong collaborations with national and international research centres.
[232] They design and manufacture vision inspection high-tech technologies in order improve the quality of the baking process, maximizing productivity, optimizing processes and reducing wastes.

"A high level of sophistication implies a high dependency from the outside. Investments in high-tech activities require an education system able to adequately train the new generation of employees; we found difficulties in hiring young people with an open-minded multidisciplinary approach; whereas the quality of the Italian education system is one of the highest in the world, more efforts should be put in training students to working experiences starting from the secondary school; I think that the shift towards 'Industry 4.0' will imply in the short term a downturn in the labour market, due to the fact that not every company is ready to combine high investments in machineries with investments in high-skilled human resources" (Technical Manager, High-tech company).

Innovation approach: main partners involved and funding tools

Each of the six companies interviewed are very internationalized, with percentages of exports on total revenues around the 80%, except for the small company specialized in electrical installations, which, however, started recently a process of internationalization.

The nucleus of 'traditional' companies, characterized by relatively low level of employees with a tertiary degree, between the 10% and the 30%, has a low level of propensity to cooperate for innovation projects; for these enterprises, the main partners for innovation activities are prevalently clients from the private sector and suppliers; they have weak relationships with the other players of the local system in particular with Universities and research centres; they generally agree around the lack of proper support and 'pro-activeness' of Universities and research centres and of the public actor in general.

On the contrary, the other three small high-tech and KIS enterprises having a relatively high level of employees with a tertiary degree (around 40-90%) and considering education and training as fundamental issues for their strategic business tend to collaborate more with Universities and research centres for innovation projects. These companies appreciate the innovation system in Trento, in particular due to the presence of excellent research centres. According to funding tools, they benefit of the supports provided by the Law 6/99, which is however becoming too bureaucratic, suggesting the need to adopt private sources of funding, like accelerators[233]. The lack of internal demand seems to be one of the main obstacles for their business activities. The critical aspects of Trento's innovation system underlined are the following: the inability of the business environment to absorb sophisticated technologies both at local and national levels, the need of the system to adapt the level of competences needed and to reduce the distance between high school education and the job experiences.

[233] Industrio Ventures is an example of successful private accelerator which currently is supporting ten innovative high-tech start-ups in Trento.

The ICT sector

In Trento, the ICT sector contributes for around the 4% of the total added value, taking into account the primary sector, the manufacturing industry and services. In order to improve the level of connectivity of local enterprises in disadvantageous areas, Trento is provided with 800 km of optical fibre and over 700 points of wireless access serving the total population with broadband services. The 57.4% of the families (against the 48.60% of Italy and 67% of the EU countries) and the 96.9% of the enterprises with over 10 employees have access to fixed or mobile large band (PAT, 2016).

Due to its transversal function, ICT has not been indicated as a RIS3 area, but as a KET, together with industrial biotechnologies, photonics, advanced manufacturing systems, advanced materials, micro-nanoelectronics and nanotechnologies.

The main players involved in the system are the following: the Department of Engineering and Information Science of the University of Trento; the ICT centre in FBK; the “Data Centre Unico Territoriale” a project for a single data centre, with the purpose to rationalize infrastructures and promote services at low energy consumption, using cloud computing; the main players of the project are: PAT, the “Consorzio dei Comuni Trentini”, the Local Agency for Health Services A.P.S.S, the University of Trento, HIT, FEM, FBK and Informatica Trentina. Among the main objectives of this program there are: the improvement of the reliability of the telematic services; the decrease of the costs and the impacts of the existing data centres; the creation of an excellence centre in which services can be accessible to private enterprises (RIM, 2012). As for the international network, Trento is the unique Italian node hosting the EIT ICT Labs, as already mentioned.

The research on the field took into account a sample of 7 enterprises: 1 large low-tech large enterprise[234], 3 micro enterprises and 3 start-ups in the KIS sector (Table 48).

Table 48: Share of the firms interviewed in the ICT sector by NACE code, type, legal form, technological intensity and type of management

NACE Code description	Type	Legal Form	Tech-Intensity	Family-owned and managed
3320-Installation of industrial machinery and equipment	1 Large	1 Public Company	Low-tech	No
6201-Computer programming activities	2 Start-up	2 Limited Companies	KIS	No

[234] This company will be described in the section dedicated to the business case studies.

6202-Computer consultancy activities	2 Micro	2 Cooperatives	KIS	No
6209-Other information technology and computer service activities	1 Micro	1 Public Company	KIS	No
7219-Other research and experimental development on natural sciences and engineering	1 Start-up	1 Limited Company	KIS	No

Source: author's elaboration

The approach to Industry 4.0

The interviews to the start-ups revealed the high potential of Internet of Things (IoT) applications in different sectors: health-care, environmental sustainability and retail and industry.

The first start-up is specialized in sensor devices for rehabilitation; IoT solutions make it possible to implement self-monitoring rehabilitation systems in the health care sector, to monitor hives and gather data concerning bees' behaviours and meteorological conditions, in the agriculture sector; to monitor buying behaviours of consumers and of employees in order to improve the efficiency of production and organizational processes in the industry and retail.

"The purpose is to provide to hobbyist and professional beekeepers and to research institutions with a system allowing a complete monitoring of the apiary. The possibility to have access to data concerning the progress of the apiaries is a true need, both to have a more precise knowledge of the bees' system biology and to improve the efficacy of the care operations of the colonies (...) it is a possible way that in the long term will contribute preventing apiary extinction" (Founder, Agriculture Start-up).

"Nico Rosberg started winning Formula 1 championship since he began to do data mining. Our company provides to our clients this important source of competitive advantage: business data analytics, able to improve, for example, the knowledge and understanding of how shoppers interact with products on display in its physical stores, of how employees perform their duties and how safety at work may be improved; the access to such type of analytics could prove an important booster for the overall companies' profitability" (Shareholder, Business Analytics Start-up).

One of the main challenges for these start-ups is the refinement of the algorithms' level of sophistication in order to be able to make predictive analysis, important additional services for clients.

"We have 130 different products detecting every day large amounts of data from human bodies, which are legible and may be interpreted more and more in order to understand if rehabilitation exercises

are well done or not and to match the type of exercise done to the particular characteristics of each human body" (Founder, Medical Devices Start-up).

One of the main difficulties faced by these start-ups is the final users' technology barriers.

"The main difficulty has been to sell an innovative product to a market, which is not digital per se; we deal with beekeepers, who often don't even use computers, do not have the minimal idea of what Internet of Things is and whose main interest is to produce honey" (Founder, Agriculture Start-up).

"It is difficult to standardize when you deal with the human body. Technology helps standardizing. But this needs to be done in a simple way. Usability standards have grown considerably, due to companies like Amazon and Google, which have based their competitive strategy on easy access technology; keeping the good equilibrium between functionality and usability is not an easy task" (Founder, Medical Devices Start-up)."Our task is to raise awareness among companies about the enormous amount of data they generate but are not adequately exploiting" (Shareholder, Business Analytics Start-up).

A similar innovative attitude is expressed by one of the micro-companies interviewed specialised in digital open platforms. They developed for the Pubic Administration an innovative project, Comunweb, involving the overall consortium of Trentino municipalities. The project manages nearly a million of structured documents, providing about 4.000 dataset with high quality data, according to the Open data paradigm, positioning the project among the first at national level, in terms of level of accessions and managed documents.

"The project represents a real 'ecosystem' with a high potential in the field of communication and on line services, integrating citizens (tourists, associations, enterprises and other subjects living in urban centres and in peripheries), which can use multiple channels to dialogue with the local entities, and a community composed by administrators and municipal employees, ICT experts and legal experts, collaborating actively one with each other. The strength of this project has been the ability to cooperate with the entire network of local stakeholders and not only with the single entities. Forum PA[235] has indicated this project as a best practice at national level, source of inspiration for other Italian regions".

Approach to innovation: main players for innovation and funding support

The large firms, startups and micro companies developed as spin-off from FBK are characterized by a strict relationship with Universities and research centres, which are constant partners and supporters of their innovative projects, independently from the size of the companies involved, receiving public funding at local, national and European level. The only company, which does not have relationships with research centres and Universities, is the micro-company specialized in open data software, which mainly operates with the Public Administration.

[235]See: http://www.forumpa.it/progetto-comunweb-la-collaborazione-fa-risparmiare-14-milioni-e-porta-innovazione-sui-territori. Trento has been awarded in October 2013.

The start-ups interviewed agree on the following strength and weaknesses of the innovation system in Trento; the main strength is the public efforts in creating an environment which is favourable for innovative activities; the consistent initial funds which make it possible for these activities to develop; the presence of important players on the territory, like research centres and private accelerators, which are proactive players on the territory. The main weakness is represented by an innovation policy which supports start-ups in the initial phases but abandons them in the following ones, which are often decisive for the success of these business activities; moreover, the pervasiveness of the public actor on the territory may represent a limitation for business activities to fully develop. Often, the difficulty to develop sales and distribution channels brings these start-ups to look for big multinational companies willing to purchase them. Other weaknesses underlined are represented by the lack of risk-taking entrepreneurial attitude of Trentino's companies; the need to improve problem-solving ability of these, trying to meet the needs of the local enterprises, when companies are actually available to cooperate with research centres.

"The innovations we developed would not have been possible without such research centres of excellence on the territory, but these need to be less theoretical and improve their problem solving attitude towards the enterprises" (CEO, microenterprise in ICT).

Another weakness underlined is the need to make the access to public funds for innovation activities more flexible and less bureaucratic; the location in a relatively disadvantageous area, which makes it difficult to easily communicate with the other important industrial centres.

Some significant case studies: Enginsoft, RTR Energy, Dedagroup and Aquafil

The present section contains some significant business case studies, which are worth to be further explored, since they highlight some relevant aspects of the 'Industry 4.0' debate.

EnginSoft Spa

EnginSoft Spa was founded in 1983 in Trento, thanks to Stefano Odorizzi and Alberto Mezzena, two engineers with a great passion for numerical analysis. Today, the company is a multinational consulting enterprise specialized in Simulation Based Engineering Science Methodologies[236] (Figure 41), with a wide range of possible application sectors: automotive, aerospace, rail and marine industries, oil and gas, energy, turbo-machinery, mechanics/structural, civil engineering, electrical and electronics, appliances, food and beverage, health care/biomechanics and sport/ amusement. Generating total revenue of 19 million of Euro in 2015, they employ 120 engineers who are specialized in different fields: virtual rapid prototyping, numeric simulation and optimization for the development of innovative methods and products. They are specialized

[236] Simulation Based Engineering Science involves different fields of analysis: fluid dynamics, mechanics, electromagnetism, acoustic, chemistry, materials, manufacturing, multi-body, impact, optimization and coupled analysis.

in activities with a very high value added, are characterized by a strong multidisciplinary approach[237], and invest much in education and training activities; the enterprise belongs to the MIUR "Centro di Trasferimento Tecnologico" and to the consortium "Tecnologie per il Calcolo Numerico" (TCN), also called "Virtual University", which organizes multidisciplinary courses in Computer Aided Engineering (CAE), prototyping and virtual experimentation, statistics, information technology, multi-objective and multi-disciplinary optimization.

"We are an example of an innovative enterprise with the 'head in research' and the 'heart in engineering'; an enterprise which is characterized by a high cultural capital, a 'niche' information technology, with a high level of cross-fertilization between different knowledge fields" (Chief R&D Officer, Enginsoft Spa).

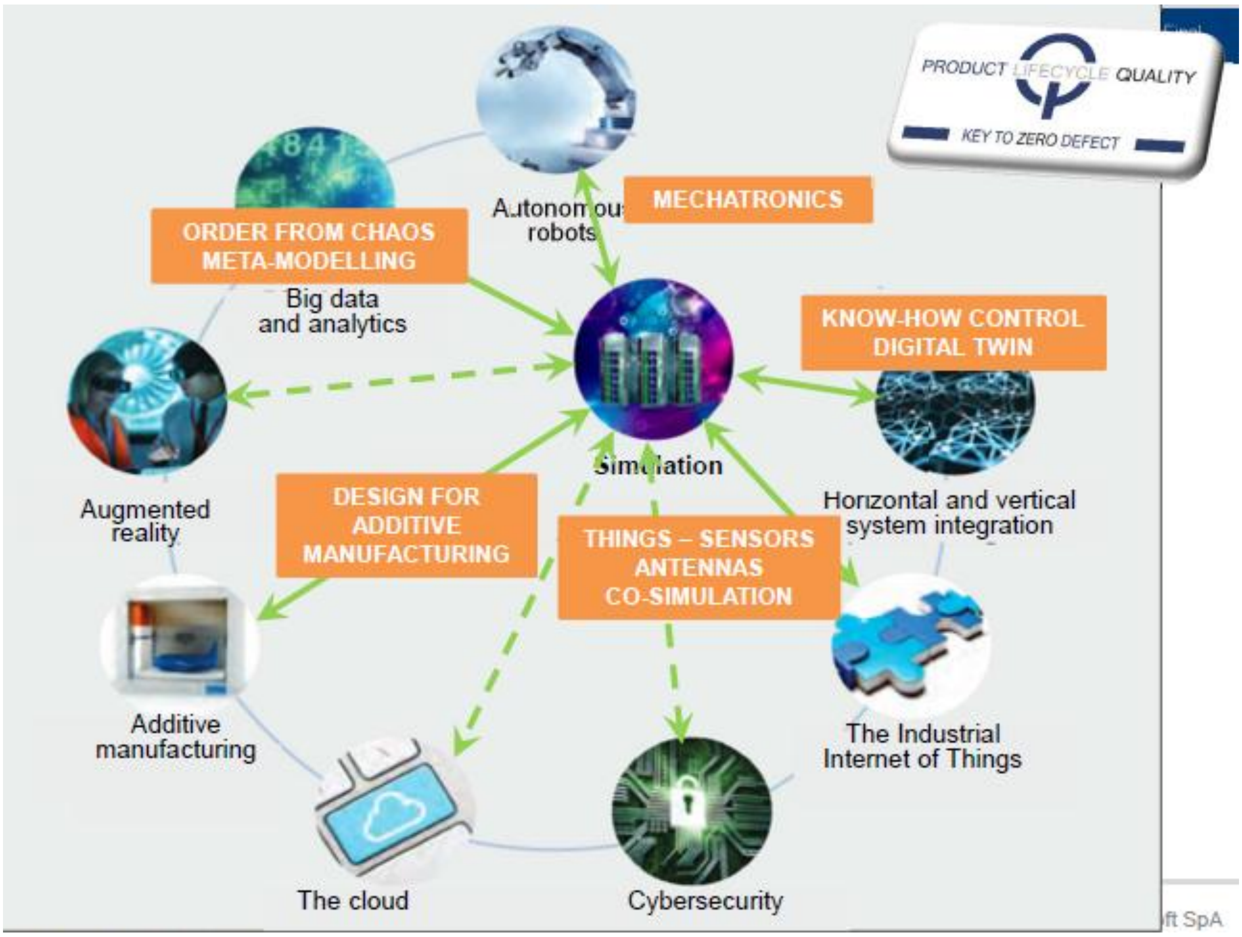
Simulation Based Engineering Science methodologies are a great source of competitive advantage for the manufacturing industry; in fact, in order for a manufacturing company to be successful on the market, the following conditions are necessary: a good and innovative idea, which needs to be translated to a concept, including the relative services, developed into the product in Time To Market (TTM) and at a low cost, optimise the productive phases in terms of quality and productivity, answer in a flexible way to the market's requests. These methodologies make it possible to perform these tasks, combining traditional engineering competences and techniques with 'computer science', mathematics, physics and social science.

"The development of new products cannot be done efficiently without the use of methodologies and technologies based on 3D modelling and on simulation processes; this represents the first step for the effective implementation of 'Industry 4.0'"(Chief R&D Officer, Enginsoft Spa).

In order for the current technological transformations to be 'inclusive', SMEs digital divide must be reduced through technologies hubs, competence centres and private accelerators[238]; these strategic PPPs may reduce the entry cost levels, benefit of scale economies and sponsorships of technical partners. These initiatives may be crucial to help start-up become possible key clients and partners.

[237] They collaborated with the 'ITT Marconi' Institute in the definition of the educational program of the school, in order to better respond to the need of 'interdisciplinary' specialists.
[238] For this reason they are partners of Industrio Ventures, which is considered a valid alternative to traditional 'public funds' supportive initiatives.

Figure 41: The role of Simulation Bases Engineering Science for 'Industry 4.0' KETs



Source: Enginsoft (2016)

Dedagroup Spa

Founded in Trento in 2007 from the fusion between two companies, Delta and Dator, both of which were born in the Eighties and joined together in 2001, Dedagroup is one of the largest Information Technology group backed by Italian capital, with a turnover of 230 million and 1600 employees. During the last ten years they faced a constant growth, with 3 data centres in Italy, 12 main headquarters in Italy, 9 all over the world, 3600 clients in 40 different countries. The main mission of the company is to become a 'platform' combining core digital application in four main sectors: public sector and utilities, banking and insurance, fashion factory and industry.

Figure 42 shows some main key principles of their business strategy. The company is aware that it is facing a change in paradigm, from the 'industrial' era to the 'digital era', from artisan excellence to differential marketing, from products able to 'sell themselves', to products 'selling' unique experiences, from Business2Business (B2B) to Product2Product (P2P) and sectoral hybridization; from the physical factory to the digital contact, from the importance of intuition and instinct to data-driven organization. For this reason, the company is implementing a strategy based on some main principles: the "Customer Journey", enhancing the customers' experience in the 'digital interaction' era, "Open Any Data", interaction tools for sharing data opening traditional environments to the digital interaction; "Operation 4.0", technologies and sensors supporting the 'operative' transformation of production and the interaction with final clients; "Digital Component Lifecycle", components and services for the digitalization of processes and documents for a long term conservation; "Architecting for Digital business", based on the need to rethink sourcing and IT governance, analytics and security supporting the digital transformation. They invest in R&D activities more than the 4% of the total revenues, in the development of new products and services in the Insurance, Fashion, PA, Banking and Business Integration Platform.

According to the Director Technology & Innovation, the prevalence of micro and SMEs in Italy represents a challenge for the introduction of advanced digital technologies to monitor the entire product's life cycle:

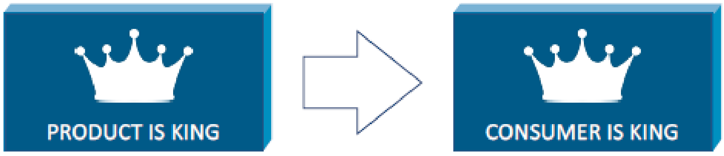
"The Italian industrial system is lagging behind the 'digital transformation'. The main obstacle to the implementation of Cloud Computing Services and Big Data Manufacturing Analytics is represented by the lack of inter-operability among diverse information/communication systems[239]; this transformation is still in its initial stages of development" (Director Technology & Innovation, Dedagroup Spa).

As already mentioned, in order to solve the problem of 'interoperability', improving the level of participation of the local enterprises to these changes, Dedagroup is involved in a strategic Co-Innovation Laboratory with FBK sharing the competence for the development of good practices for data inter-operability and openness and for the realization of a new generation digital applications.

"One of the main characteristics of this change in paradigm is the high speed of technological evolution; digitalization implies a structural change in the economy and in the labour market. It is not just a matter of SMEs, but of strategic policies adopted in Italy, which needs to understand that heavy investments in digitalization will in the short term imply a loss of workers, but in the long term, boost the manufacturing industry, reaching one of the highest levels in Europe. In order to be at pace, the entire system and not the single individuals must be involved" (Director Technology and Innovation, Dedagroup).

[239] In the present stage, interoperability represents the main challenge. Cyber-security is not much of an issue; the problem for most clients is to keep the right balance between an adequate level of security and an adequate level of flexibility; for example, many clients are ready to give up to some "security" in order to have more flexible services.

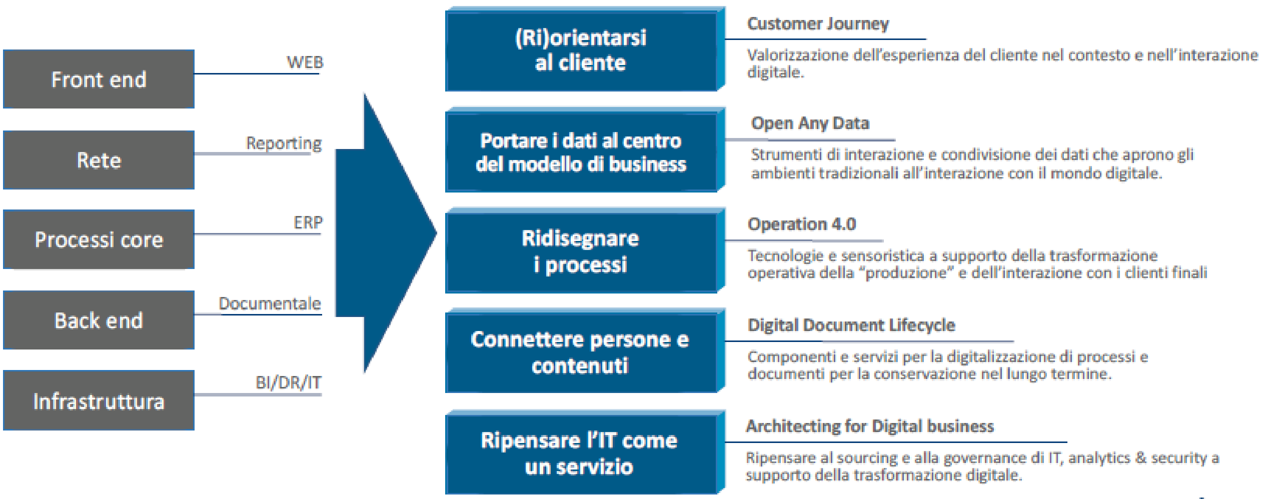
Figure 42: The shift from the 'Industrial' to the 'Digital' era



ERA INDUSTRIALE	ERA DIGITALE
Eccellenza artigianale	Marketing differenziante
Prodotti «che si vendono da soli»	Prodotti che abilitano esperienze uniche
B2B, B2C	P2P e ibridazione settoriale
Fabbrica	Punti di contatto
Intuizione e istinto	«Data driven organization»

Source: Dedagroup (2016)

Figure 43: Main business areas of Dedagroup



Source: Dedagroup (2016)

Rete Rinnovabile

Rete Rinnovabile is a company of RTR Capital, owned by the English private equity fund, Terra Firma. RTR Capital is the first producer of sun renewable energy in Italy, with 11 enterprises and 165 million Euro of total revenue; it is a leader in renewable energy also in Europe, in terms of power energy installed, with 117 plants and 318 MW products. Rete Rinnovabile is located in Progetto Manifattura since 2015 and it is a highly innovative company. The company chose to locate RTR Energy inside Progetto Manifattura, attracted by the advantages this project offers in terms of cross-fertilization, the possibility to benefit from funding support and to have access to the high level of education system. For this company, the main source of competitive advantage is the adoption of a unique centralized system, able to monitor remotely all the plants, generating automatic reports describing their trends in order to manage them efficiently.

"The possibility to monitor from a centralized 'brain' the high number of plants spread throughout the whole Italian territory constitutes the main source of competitive advantage with respect to our competitors; it makes it possible to reduce wastes and increase plants' level of efficiency" (Chief Operating Officer, RTR Rete Rinnovabile).

The 'great challenge' for this company is to be able to improve the management of Big Data coming from panels (temperature, power, electrical and physical parameters) in order to reduce the 'level of unpredictability' of this sector, which is very influenced by the 'unstable' weather conditions. Universities and research centres are the main players of innovation, funding prevalently with internal resources its R&D activities.

Aquafil

Founded in 1965 in Arco, Aquafil is a leader company in the field of synthetic fibre production especially in polyamide; in 2015, the company had 538 employees and total revenue of 534 million of Euro. The group is made of 2.700 collaborators, has 16 plants in 3 continents and 8 countries: Italy, Slovenia, Croatia, Germany, UK, U.S., Thailand and China. It operates mainly in two business units: Bulk Continuous Filament (BCF), especially used in contract, automotive and residential sector and Nylon Textile Filaments (NTF), used in clothing and sport industries.

The digitalization process for this big company started many years ago; the first "4.0" experiment dates back to 1999 in a PhD project.

"The intuition was to realize a software able to predict the changes in the plants' parameters setting, linking sensors to algorithms, in order to prevent malfunctioning, increasing the quality of products and processes; today, the challenge is tough: sensors have become much more sophisticated and less expensive, with very high calculus capacity" (CEO Aquafil).

Today, the challenge is to improve the algorithms' level of sophistication, improving the predictive ability and machines' simulation processes.

"In the future what will make the difference will be the capacity to realize sophisticated algorithms able to predict and simulate reality" (CEO Aquafil).

For this reason, the company is hiring mathematics and physicists because today innovation processes will require more and more cross-fertilization mechanisms between different knowledge domains and competence areas. For this purpose, they are developing strategic collaborations with Universities finalized at training key figures able to interpret the future challenges. The presence in the Italian country of excellent research centres and Universities represents a crucial asset for the current technological revolution, which needs to be fully exploited.

"What needs to be improved in our industry-academia interaction model is not our approach to the educational system, since the quality of our graduated students is one of the highest in the world, but, on one hand, the approach of our Universities, which need to be more close to companies' concrete needs, and, on the other hand, the open-mindedness of our companies, which need to be more confident in our Universities' ability to create added value" (CEO, Aquafil).

Table 49: Summary of the results of the interviews

Sector/Dimension	Level of adoption of 4.0 KETs	Approach to collaborative innovation and funding tools
Agrifood	Highly advanced 4.0 technologies adopted independently from the size (IoT for Smart Vineyards) thanks to fruitful collaborations with the local research centres. Only LEs use RFID to monitor or control industrial production, SCM and cloud computing services; no adoption of Advanced Automation, Advanced HMI and Additive Manufacturing.	Relatively high propensity to cooperate with Universities and research centres for highly innovative projects (mainly for process innovation); the attitude towards innovation depends not much on the size, but on the levels of firms' absorptive capacity. What matters most for innovation are not the Provincial financial aids but being located inside the innovation system of strategic players (mainly research centres).
Mechatronics - inside the Hub	High level of specialization in 4.0 KETs (IoT, Big Data Analytics, cloud computing services, Advanced Automation, Advanced HMI, Additive Manufacturing)	Relatively high propensity to cooperate with Universities, research centres and technical institutes. The possibility to have access to the network of strategic private and public players is the primary reason for these companies to locate inside the Hub. Funding support is an important but still less relevant motivation.
Mechatronics - outside the Hub	The nucleus of "traditional" companies show some difficulties in meeting the '4.0' challenge (low level of adoption of IoT, Big Data Analytics, cloud computing services, Advanced Automation, Advanced HMI, Additive Manufacturing) for some main reasons: lack of support from the system, lack of a clear strategy, small company's size, lack of adequate technical skills.	Relatively low propensity to cooperate for innovation activities with other partners, especially with Universities and research centres; the players involved in innovation activities are prevalently suppliers and clients from the private sector. They act in isolation from the other players of the local innovation network.
	The nucleus of "innovative" companies is highly specialized in the 4.0 KETs facing some critical issues: the need to maintain a 'market-oriented' attitude, despite the high level of sophistication of their technologies and the need to adopt the internal skills to the fast changing technological environment.	Relatively high propensity to cooperate with Universities and research centres for highly innovative projects; they benefit of the Provincial financial aids, which are, however, linked to too bureaucratic procedures. They are moving to more private sources of funding, like private accelerators.
ICT	High level of specialization in 4.0 KETs (especially IoT solutions applied to health care, environmental sustainability and retail and industry). The main barrier they are facing is the incapability to develop an internal market and the need to face the final users' technological barriers.	Relatively high propensity to cooperate with Universities and research centres for highly innovative projects; they have benefited of the Provincial financial aids supporting the initial phases of development of the start-ups, but stress the possible risk of fragmentation and waste of funds this policy may create.

Source: author's elaboration

4.3. Discussion and final remarks

The present section discusses the results of the qualitative analysis, in light of the initial research questions, RQ 3, divided in the two main sub-questions, RQ 3a and RQ 3b, discussed, respectively, in paragraphs 4.3.1. and 4.3.2., and RQ4, discussed in paragraph 4.3.3.:

RQ 3: In the context of an institutional-driven RIS, what are the elements of the institutional/organizational framework which are able to positively influence local technological development, favouring the technological shift towards 'Industry 4.0'?

- *RQ 3a: What are the structural elements (knowledge generation and diffusion subsystem, the regional policy subsystem, the local interactions between the relevant dimensions and the socio-institutional factors) of the RIS favouring/blocking local technological development?*

- *RQ 3b: How are the local firms and institutions approaching the shift towards 'Industry 4.0' and what is the role of strategic PPPs in favouring this shift?*

RQ 4: Is a top-down approach to innovation policy sufficient to trigger the cross-level synergies between the players of a RIS influencing the local technological development and thus favouring the socio-technical transition towards Industry 4.0?

4.3.1. The analysis of the case study in the RIS framework

RQ 3a: What are the structural elements (knowledge generation and diffusion subsystem, the regional policy subsystem, the local interactions between the relevant dimensions and the socio-institutional factors) of the RIS favouring/blocking technological development at the local level?

Figure 44 here below shows Trento's innovation system, drawing on the works of Autio (1998) and Tödtling and Trippl (2005), distinguishing between the following structural elements of the RIS: regional policy subsystem, knowledge generation and diffusion, knowledge exploitation, with local interaction represented by thick/thin arrows indicating strong/weak internal and external ties. Table 50 summarizes the main elements emerging from the analysis of the case of Trento, evaluating each strategic function and the related blocking mechanism. It draws on the framework of Hekkert et al. (2010), contained in Wieczorek and Hekkert (2012).

Knowledge generation and diffusion subsystem

The knowledge generation and diffusion subsystem in Trento is very strong and rich in infrastructures, Universities, research centres, innovation agencies and technological hubs; the variety of knowledge domains and the high quality of the research institutions and educational institutes made it possible for the city to attract many foreign students from abroad and to enter into both national and international circuits of knowledge, becoming a prestigious centre of excellence at international level. The University of Trento, FBK and FEM are the main players of the knowledge generation and diffusion subsytem, with one of the highest rates of application to research projects in the Seventh Framework Programme and Horizon 2020 and being the only city in Italy hosting the ICT node of EIT and being partner of the KIC in raw materials.

The analysis of the main projects conducted inside FBK, in particular in the ICT and in the CMM centres, whereas confirming the high level of participation of the research centre to European projects, reveals also the increasing involvement of the foundation in R&D collaborations with prestigious worldwide multinationals in Europe (Germany) and in extra-European countries (Japan and U.S.), attracted by its high level of expertise in ICT and in 'smart microsystems'. Relevant external influences come from the Vanguard Initiative (Trento is observer of the initiative since December 2016 and officially became a partner in November 2017), which includes as members other important manufacturing Italian regions, as Lombardy and Emilia Romagna, and from the Cluster Nazionale Fabbrica Intelligente (CNFI) at national level.

Also the educational institutes, ITT Marconi and CFP Veronesi, are relevant players on the territory, strictly cooperating with FBK, through the FBK-Junior project, developing projects aimed at raising the interest and awareness of the new generations towards issues related to scientific research; moreover, they cooperate with other players of the system, for example with one of the main BICs on the territory, Polo Meccatronica, and important companies on the territory, like EnginSoft Spa, in defining periodically the curriculum and topics to follow, according to a precise strategy which is aimed at training and educating future employees following a cross-fertilization approach between mechanics, electronics and information technology. According to many companies interviewed, this particular combination between the high level of research centres on the territory and the access to high qualified human capital represents one of the main sources of attraction of Trento's innovation system, which is difficult to replicate in other areas of Northern Italy.

Despite the creation of a solid and highly attractive knowledge generation and diffusion subsystem, the exploitation of the research results and knowledge transfer activities still represents a challenge for the local innovation system. In this respect, the interviews to the relevant players of the local system have revealed some main critical issues.

A first critical aspect concerns the lack of clarity of the research centres' mission. FEM and FBK are supposed to be at the same time centres of excellence in scientific research and centres for technological transfer for local development, being required to maintain high standards in both basic and applied research.

Whereas the coexistence of these purposes led these research centres to become important centres of excellence at international level, some concerns are raised about the sustainability of this model in the long run; the more and more restricting self-financing conditions, also given by the current economic crisis, is leading many research units to look for external sources of funds concentrating more on applied research, to the detriment of basic research; given that today's technological transfer is based on yesterday's basic research (Bozeman, 2000), the lack of a proper internal organization and well specified mission may lead to a mismatch between basic and applied research and to the loss of competitive advantage in the long run.

The lack of clarity in the mission and the hybrid nature of the organization, between a public University and a private research centre, introduce a second issue related to technological transfer, concerning the players in charge of technological and knowledge transfer activities. Several heads of units in FBK have questioned the effective utility of the 'intermediate' agencies in charge of technological and knowledge transfer activities. In fact, excluding the participation of FBK to European projects, the most prestigious projects realized with the industrial partners have been realized thanks to the involvement of the heads of units in the network of international relationships built over the years. According to them, the scientific skills and competences are the most effective 'marketing channel' able to attract solid business relationships: it is only through a scientific research background that it is possible to communicate effectively research findings; what matters most for a proper knowledge sharing and technological transfer is the reputation of single research teams and their consolidated network of informal relationships.

Except for the project managers which have developed also 'commercial skills' during the time, researchers generally lack of a commercial attitude able to effectively promote the research results; they are often evaluated in terms of the number of publications, so that they are not sufficiently stimulated in pursuing knowledge sharing activities. This approach is different from the one adopted by other research centres, like the Fraunhofer Institute, for example, for which researchers must be trained to be also 'promoters' of their research findings.

In this regard, Dominik Matt, the Director of the Fraunhofer Italia Research Institute, has provided an interesting observation:

"Our researchers must be educated to follow research projects managing the whole process, from the ideation, to the design and technological transfer, following the philosophy of the founder, Joseph von Fraunhofer, who has been contemporarily a researcher, an inventor and an entrepreneur. He invented the spectroscope, developed the diffraction grating and invested in a private company specialized in optical instruments. The researchers of the Fraunhofer Institute approach technological and knowledge transfer, taking care of the promotion of innovative projects, the acquisition of new clients, the delivery of projects and the final reporting"(Dominik Matt, Director of the Fraunhofer Italia Research Institute).

Moreover, the complex and hierarchical structure of the foundation and the plurality of knowledge domains may hinder the overall efficiency of the organization: there are some difficulties, on one hand, in a proper level of communication between the different research units and, on the other hand, in the attraction and promotion of new business relationships from outside.

Finally, the surrounding business structure with a limited capacity to absorb FBK's highly sophisticated technologies produces a consistent brain drain phenomenon of skilled human capital, that will be further discussed in the following paragraph.

Knowledge application and exploitation subsystem

The orographic condition of Trento is the main responsible for the moderate development of a solid industrial structure, which is characterized by the prevalence of micro and small enterprises, with the service sector accounting for the 73.1% of the total value added, against the industrial compartment accounting only for the 23.5%, mainly in agriculture and mechanical industry with a limited capacity to create a critical mass of enterprises. The geographical location, whereas facilitating the business relationships with the Central European network of companies, represents an obstacle for reaching the most dynamic and innovative urban centres. In fact, there are many examples of multinational companies which decided to leave the Province during the years, like Michelin and Whirlpool. The specific orography of Trento's territory and business structure's composition explain why the private component of the total R&D expenditure on GDP and the patent applications are relatively low in comparison to the Italian and to the European levels. According to many interviews, the presence of risk-averse companies is imputed also to the presence of a strong public actor, which is too much involved in the innovation system: the dependency on the local government as a source of funding has created a 'numbing effect' on companies.

Despite some difficulties in the creation of a solid industrial system, there is a relatively high level of dynamicity in many SMEs on the territory; it is the case of some companies in the mechanical industry, past subcontractors of big multinationals that, during the time, have been able to reconvert themselves towards mechatronics, encouraging the Province to invest heavily in this sector. Moreover, there are some examples of companies counting on some niche sectors, like for example the company 'La Sportiva' based on the production of hiking shoes and market leaders like the Nylon producer 'Aquafil'. Interesting spinoffs from research centres in particular in the ICT sector are today fully developed companies, playing an important systemic function on the territory, working on projects which are able to increase the overall technological level also of the low-tech local companies, in particular in the agrifood sector.

Given the predominance of the agrifood and of the mechanical industry, the business structure is characterized by the prevalence of a synthetic knowledge base which usually characterizes industrial machineries or food processing; this type of knowledge is particularly linked to incremental innovations and relies more than the analytical one, on the DUI mode of innovation (Asheim and Coenen, 2006). This may partly explain why there is a relatively low level interaction with research centres which are characterized by a more analytical knowledge base.

In this context, Polo Meccatronica and Progetto Manifattura represent important opportunities for the development of a cluster of companies in mechatronics and renewable energy, which will be strategic sectors in the 'Industry 4.0' technological framework. These poles attract high-tech start-ups, incubators and research centres of large companies, thanks to the possibility to have access to a cross-fertilization environment and to a wide range of skills of extremely high quality, difficult to replicate elsewhere. Industrio Ventures, the private accelerator supporting the most innovative start-ups in the ICT and high-tech sectors, seems to be a particularly positive experience in this direction. The level of absorptive capacity of the enterprises, the presence of a precise business strategy, are the most important elements characterizing the companies which find convenient to locate inside the hub. On the contrary, the companies which don't have an adequate level of 'cultural background' and strategic vision have higher difficulties to interact with each other and to recognize advantages in being located inside the hub.

Regional policy subsytem

The vision of early policy makers who in the past made strong investments in cultural development and scientific knowledge has been crucial in orienting the Province towards a development trajectory based on research and innovation, strongly supported by the financial and special status autonomy[240]. In fact, Trento has been one of the first Italian and European cities that effectively adopted an innovation policy a long time before this term entered into the academic and policy debate.

During the years, the Province has been able to adapt its innovation policy from a top-down 'science-based' approach to a bottom-up 'smart specialization' approach. The Province has shown the ability to interpret the signs of 'entrepreneurial discovery' coming from the business world, supporting strategic projects like Progetto Manifattura and Polo Meccatronica, following the suggestions and intuition of a group of dynamic entrepreneurs who recognized mechatronics and renewable energy as promising sectors. Today, the Province provides government regulation and financial support to all the players of the innovation system ensuring a good level of communication between the different agencies, facilitated also by the small dimension and the presence of many informal relationships. The presence of a clear strategic vision makes it possible to coordinate efficiently the research centres, the educational institutes and the public agencies. In this context, Trentino Sviluppo plays a very important role in bridging the main players of the innovation system and attracting foreign investors from outside. Recently, the Province indicated HIT as the 'systemic actor' responsible for the technological and knowledge transfer activities between the industry and the academia and for the participation to European projects. As for the infrastructural structure, Trentino Network and Informatica Trentina make it possible for the entire system to benefit of efficient telecommunication and ICT infrastructures.

Whereas the strong presence of the public institutions facilitates a precise strategic orientation through the effective coordination between the players of the system, the pervasiveness of the public actor in the system may represent an obstacle for its full innovation potential. Too much involvement of the public actor in most of the activities, together with the lack of internal demand, is perceived as an obstacle for the the development of an internal market. Moreover, too much dependency on local government as a source of

[240] This has been true especially during the Nineties, where the strong investments in the ICT sector stimulated the creation of an ICT eco-system.

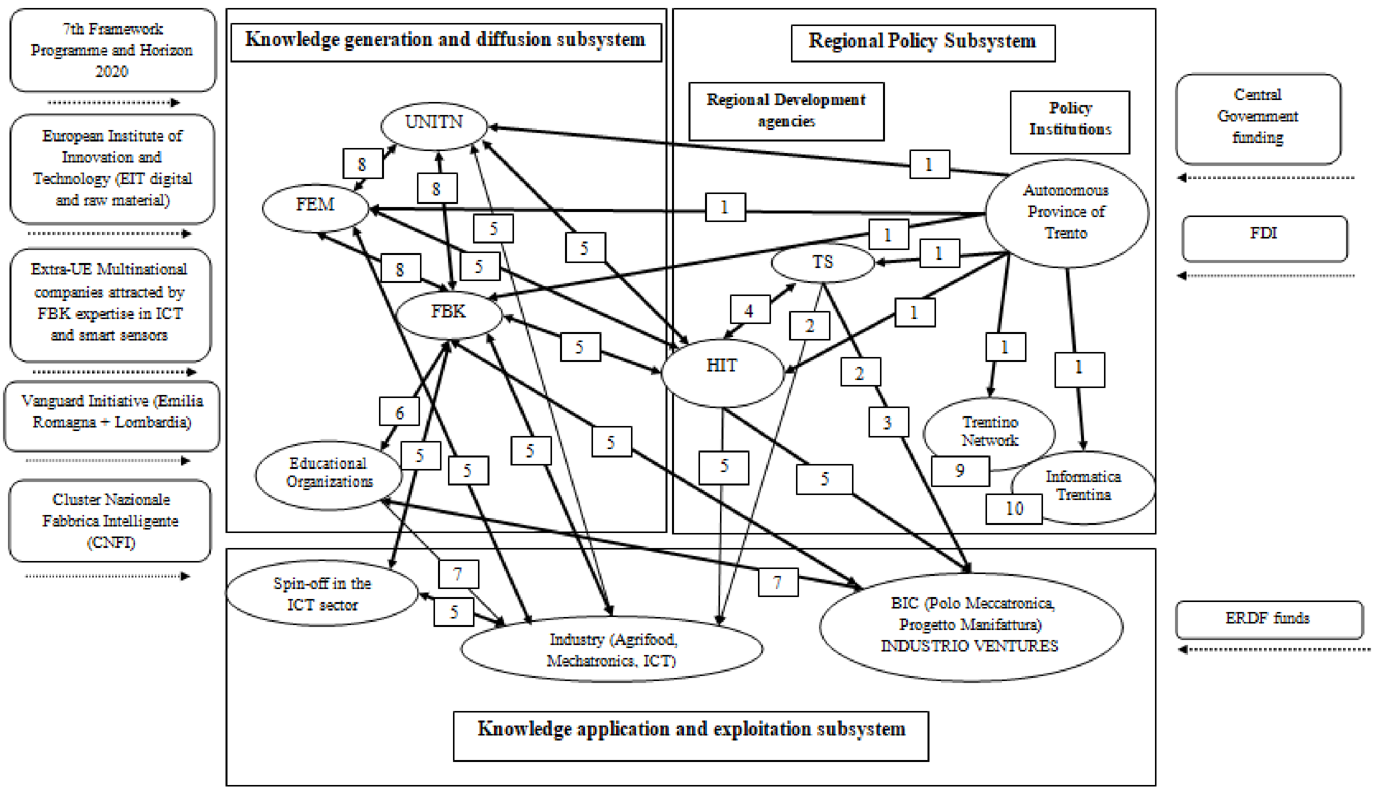
funding for R&D activities may threaten the sustainability of the system in the future, especially in periods of economic crisis and decrease of public funds for R&D activities. Finally, the historical opposition between the scientific community and the industry around the effective impact on the territory of research investments doesn't seem to have found a solution. Still, the local community perceives policy institutions as hierarchical, 'self-referential' and distant from their concrete needs. In addition, while the Province continues to support business innovation activities through policy tools, like the Law 6/99, some concerns are raised by the companies on the high level of bureaucracy of these procedures and on the difficulties related to the need to anticipate the financial investments of the R&D projects.

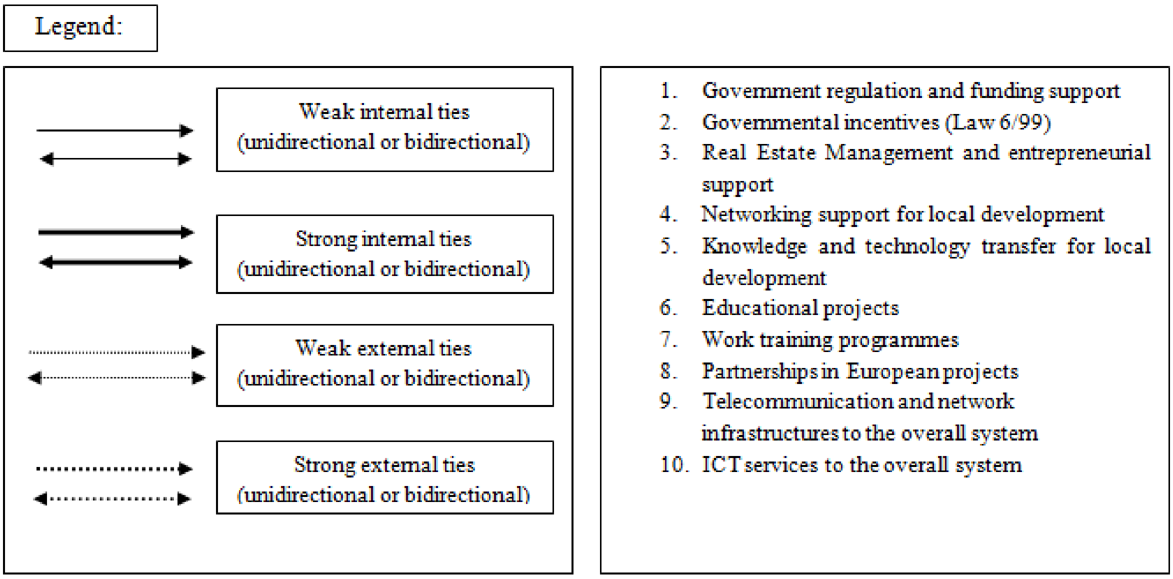
Local interaction and social cultural factors

The small territory facilitates the close collaboration between the 'regional policy subsystem' and the 'knowledge generation subsystems'; as already mentioned, the interactions between the 'knowledge exploitation subsystem' and the 'knowledge generation subsytem' are more difficult, in part due to the high level of internationalization and sophisticated knowledge domains of the research centres, in part due to the particular composition of Trento's business structure, based on the prevalence of SMEs. However, FBK and FEM research centres are generally seen as proactive players for innovation by the local companies. External influences, in particular the participation to European projects, has had an important impact on the local territory, stimulating strong investments in strategic sectors like ICT and Mechatronics.

From a social point of view, a strong cooperative culture characterizes Trento's society and economy making it possible for key players to develop especially in the agrifood sector.

Figure 44: Trento's innovation system





Source: author's elaboration

Table 50: Functional-structural analysis of the RIS and identification of the blocking mechanisms

Function	Function's evaluation	Blocking Mechanism (Reason why the specific function is absent, weak, strong)
Entrepreneurial activities	Prevalence of micro and small companies in the service sector; some big multinationals in the manufacturing sector have left the city in the past; however, there are some examples of dynamic companies, mainly in agrifood and mechatronics. The territory attracts particularly research centres of large companies.	The particular orography and the relatively small portion of territory that can be dedicated to production and urban activities hinder the development of a solid industrial system.
Knowledge development	The knowledge base is rich in terms of number of research centres (both basic and applied) and variety of research fields on the territory. Many of them have international leading positions with a high level of published articles and of participation to European projects. The local public actor and the international partners mainly finance Trento's knowledge development.	The hybrid nature of the foundation, like FBK, between a private entity and a public University, requires keeping high standards both in basic research and in technological transfer: risk of mismatch between basic and applied research. Low capacity of the business structure to absorb the sophisticated technologies: risk of brain drain of human capital.
Knowledge diffusion	Research partnerships are prevalently with European and extra-European industrial partners.	The mismatch between the analytic knowledge base of the research system and the prevalence of a synthetic knowledge base of the industry makes it difficult for these two subsystems to interact. TTOs functioning must be improved. Low propensity of local companies to invest in R&D activities.

Guidance of search	The policy vision is clearly and properly defined, supported by specific programmes and strong investments; the system's frontrunner is the Province of Trento, which is involved in the government regulation and funding support of all the players of the innovation system.	The local community perceives policy institutions' strong investments in research and education in contradiction to the needs of the system. Risk: too hierarchical and self-referential attitude of the policy maker.
Market formation	There are dynamic companies dominating some niches and also some market leaders, however the system struggles for the creation of an internal dynamic market.	The lack of internal demand and too much involvement of the public actor in most of the activities on the territory are perceived as obstacles for the creation of a internal market.
Mobilization of resources	Public funds have always been abundant, due to the special autonomy of the Province and have been particularly oriented in supporting the research and innovation system; the access to European funds represents an important channel for maintaining the system at the frontier of technological innovation; however, public sources for R&D activities are shrinking, and this may represent a challenge for the future sustainability of the overall system.	Too much dependency on the local government as a source of funding for R&D activities is a challenge for the future sustainability of the system. The access to public funds for innovation activities (Law 6/99) is perceived as too bureaucratic (firms need to anticipate the financial investment) and companies are more and more shifting to alternative private funding supports (e.g. private accelerators). Heavy supports to start-up create fragmentation and waste of funds.
Creation of legitimacy	High investments in research have contributed to create a centre of scientific excellence; however, they have always been perceived by the local community as a critical issue. Too much concentration of power in the public actor may imply some problems in the creation of legitimacy.	The lack of a structured model of indicators accounting for the local economic impact of research and innovation investments may limit the public actor's legitimacy.

Source: author's elaboration drawing on the framework of Hekkert et al. (2010), contained in Wieczorek and Hekkert (2012)

In light of the distinction between organizationally/institutionally thick/thin RISs (Tödtling and Trippl, 2005; Trippl et al., 2015a), the case of Trento can be categorized as an 'institutionally thick' but 'organizationally thin' peripheral region (Doloreux and Dionne, 2008; Karlsen et al., 2011); the institutional thickness is related to the presence of solid institutions which have been able to stimulate an articulated knowledge-generation subsystem; the organizational thinness is not related to the lack of research organizations, which, as we have seen, are very developed, but concerns the weak presence of a critical mass of firms with low levels of clustering which have difficulties to absorb the high concentration of sophisticated knowledge generated by the different players of the knowledge generation subsystem.

Interesting analogies may be identified with the case study of La Pocatière, illustrated in the work of Doloreux and Dionne (2008). As La Pocatière, also Trento may be considered as an example of peripheral region which has been able to deal with the problem of organizational thinness through the development of an institutional-driven RIS; the size and the orographic conditions did not represent obstacles to the emergence and development of an innovation system, which has been the result of a visionary policy making of mid-nineteen century implementing an innovation policy long time before this term entered the academic and policy debate. Moreover, the educational vocation, the high level of human capital and the excellence of the research centres represent important sources of competitive advantage of the system, supporting the hypothesis that local institutions are crucial players able to enhance the innovation potential and economic renewal of regions.

Moreover, as described in the first section, the existing literature on RISs has prevalently concentrated on linking organizational thickness or thinness to different industrial path development patterns (path creation, path renewal and path extension); in this context, the main result in the literature is that the typical development pattern for organizationally thin systems is path exhaustion, meaning that the region characterized by the lack of relevant organizations is locked into innovation activities limiting the opportunities for experimentation and space to manoeuvre in radical innovation, which, in the long term, erodes regional competitiveness. The case of Trento sheds light into some interesting considerations which may enrich this relationship. It represents an example of institution-driven RIS, which, despite the presence of organizational-thinness in terms of lack of critical mass of enterprises, thanks to the presence of solid institutions, is going towards a path renewal development process, stimulating the concentration of many businesses in mechatronics and renewable energy, which represent strategic sectors in the current techno-economic shift.

Finally, the case of Trento shows an additional aspect related to the role of exogenous and extra-local sources of knowledge for regional change. Path renewal is also triggered by the inflow of non-local knowledge and its combination with the highly specialized assets available within the region (Trippl et al. 2015b). In the context of the current shift towards a new techno-economic paradigm based on 'Industry 4.0', the extra-local connections of the local system in terms of access to national and international circuits of knowledge are essential channels and the existence of multi-scalar organizations, which continuously interact with extra-national sources of knowledge (Gertler, 2010) reveal to be essential means that may avoid technological lock-in processes and shape path renewal processes.

4.3.2. The approach of the firms and institutions to Industry 4.0

RQ 3b: How are the local firms and institutions approaching the shift towards 'Industry 4.0' and what is the role of strategic PPPs in favouring this shift?

Thanks to the visionary policy makers which made strong investments in research and cultural development and thanks to the significant influences on the system of extra-local knowledge flows, today the local research centres, in particular FBK, play a strategic role in the context of the 'Industry 4.0' debate; a significant number of knowledge domains linked both to the 'hardware' and 'software' dimensions of the 'Industry 4.0' are present in the research centre. Although the majority of the projects, both in the CMM and the ICT centres, has been developed in the context of partnerships with the European Commission, the centre counts also some important R&D projects with strategic partners, in the industrial, biomedical, aerospace and utilities sectors; the CMM centre has an important technological knowhow in the design and fabrication of sophisticated advanced smart sensors and applied research in energy systems, positioning as a strategic actor in the 'smart grid' debate and attracting important European and extra European multinationals; especially the IRIS unit is increasingly developing R&D projects with industrial partners, thanks to the support of the MNF Lab and of the clean room. However, a part from some partnerships with local enterprises, the impact on the territory is relatively low, due to the highly sophisticated technologies they offer and the relatively low absorptive capacity of the local enterprises. The important challenge FBK is facing today concerns the impact of such a high level of competences and knowledge on the territory, which shows some difficulties in absorbing these sophisticated technologies, mainly due to the prevalence, not only at local but also at national level, of micro and SMEs. In this respect, the local PPPs, described here below, reveal to be effective policy tools able to improve the system's overall level of absorptive capacity, as discussed in the paragraphs here below.

The point of view of the enterprises reveals some interesting aspects in the level of adoption of the 'Industry 4.0 KETs', which are summarized in Table 51 here below.

In the agrifood sector, the presence of a 'systemic actor' on the territory (the software house) and the pro-activeness of research centres like FBK and FEM made it possible for low-tech companies to upgrade their technological competences, adopting, regardless of the size, integrated platforms for the 'smart management' of their vineyards, optimizing the production processes and the quality of their products. The main advantages linked to these projects are the possibility to perform automatic data collection and sharing of information, environmental monitoring with more efficient and flexible production processes. The main obstacle is linked to the need to upgrade the internal competences to manage this shift. The main challenge identified concerns the need to improve the business process management through the adoption of SCM software, which companies have difficulty to adopt, due to the highly fragmented value chain characterizing the Italian business structure as a whole, due to the predominance of micro and SMEs, as Schivardi (2016) has noticed. Only the four large enterprises have an ICT specialist, while only two of the four organize ICT training courses for the employees, confirming the general national trend, described in the previous Chapter.

In mechatronics, the group of 'traditional' companies is characterized by a high potential to become protagonists of the 'Industry 4.0' revolution, but suffer of some main weaknesses: they lack of a precise strategy able to face changes, often due to a family-managed and resistant to change approach; they are not often structured or do not feel supported by the overall system. On the contrary, the group of 'innovative' companies are characterized by a high level of specialization in the 'Industry 4.0' technologies, they are high-tech companies producing sophisticated technologies for the improvement of automatic data collection, sharing of information and environmental monitoring; these companies identify as main obstacles, the lack of demand to develop an internal market and the need to upgrade human capital skills in order to face the rapid technological advance; the main challenge for these companies is to overcome the SMEs digital divide by creating local partnerships with strategic private and public players. Among the small and medium firms interviewed, there is a minority of firms having ICT specialists and organizing ICT training courses, as already mentioned.

Finally, the companies in the ICT sector revealed the high potential of the 'Internet of Things' in different sectors: health-care, environmental sustainability and retail and industry; the advantages linked to these applications are self-monitoring in the health care sector, monitor of hives and gather data concerning bees' behaviours in the agriculture sector and monitor of consumers' buying behaviours; the main obstacles perceived are the final users' technological barriers and the lack of internal demand, with the main challenge being the development of an internal market.

The four business case studies analyzed show different aspects through which the challenge of the 'Industry 4.0' can be met: they indicate sophisticated simulation algorithms for predictive analysis as the great challenge of the nearest future and identify the adoption of a multidisciplinary approach to competence exchange and strategic partnerships with public and private players as the way to overcome the digital divide of SMEs.

In this respect, the Province, whose innovation policies share some features of the 'mission-oriented' approach, described in Chapter One, counts a number of interesting local PPPs (Table 52), which are shown to be effective policy instruments able to translate at local level the knowledge inputs of this multi-scalar framework, increasing the overall innovative potential of the RIS (Kristensen and Scherrer, 2016).

The first one is TreC, the citizen health record resulting from a successful PPP involving the Province (former Dept. of Innovation and ICT, Dept. of Health, Dept. of Social Policy), Informatica Trentina, FBK, University of Trento, University of Venice, the consortium of Trentino municipalities, local professional associations of doctors and nurses, and a local ICT company 'GPI'. As already mentioned, the project aims at providing Trento's citizens with a multi-channel access point to health services and other effective tools for the management of the health needs of their families and supporting the job of health professionals, doctors, nurses and public institutions officials in organizing in an innovative care services. "The platform supports both citizens and local health institutions in providing new prevention and care services. One of the main strengths of the approach is user engagement: TreC functioning is based on the active participation of people" (RIM, 2012, p. 20). In order to achieve the mission to create an integrated platform for healthcare services, a co-innovation lab has been created between Dedagroup and FBK, aimed at developing new standards and practices for the improvement of the interoperability of data and services (Open Data, Open Services) for the realization of new generation digital application. The purpose is to extend the concept of the medical digital record to the overall welfare services for the citizens, revealing the presence of a strategic view of the Province, which embraces all the aspects of the life of the citizens.

In order to digitalize Trento's forests, the Province activated a PPP between Trilogis, an ICT company based inside Polo Meccatronica, the Consortium of Trentino's municipalities, FEM and FBK, applying the technologies used for 'smart cities' to the completely different context of forests, woods and rural areas, which cover the 70% of Trento's total territory. Joining together the private company's software with the algorithms developed by FEM and FBK, this project will make it possible to "(...) computerise and speed up the management of a sector which is still ruled by traditional methods[241]".

Finally, the Prom Facility Lab inside Polo Meccatronica, resulting from the collaboration between Trentino Sviluppo, FBK, the University of Trento and Confindustria Trento, provides businesses in mechatronics with an integrated platform for the design, development, implementation, verification and validation of systems and manufacturing processes. The Lab is also aimed at training students of technical and professional schools in order for companies to be able to face future challenges related to the 'Factory of the Future'.

These examples show how PPPs make it possible for strategic players on the territory to cooperate creating platforms for knowledge and competence exchange, increasing the entrepreneurial capacity and the overall innovative potential of the RIS (Kristensen and Scherrer, 2016), both in terms of knowledge creation, putting together relevant structural elements for knowledge generation and stimulating continuous learning, and in terms of entrepreneurial activities, attracting strategic managers and stimulating the overall innovative capacity of the system.

Table 51: The approach to Industry 4.0 (level of adoption, advantages, obstacles and challenges) of the firms interviewed

Industry 4.0/Sectors	**Agrifood**	**Mechatronics**		**ICT**
		"Traditional"	"Innovative"	
Level of adoption	Highly advanced '4.0' KETs adopted regardless of the size (IoT for Smart Vineyards and sensors for detection of fruits' level of maturity) thanks to fruitful collaborations with the local research centres. Only LEs use RFID to monitor or control industrial production, SCM and cloud computing services; no adoption of Advanced Automation, Advanced HMI and Additive Manufacturing.	Difficulties in meeting the '4.0' challenge (low level of adoption of IoT, Big Data Analytics, cloud computing services, Advanced Automation, Advanced HMI, Additive Manufacturing).	High level of specialization in the '4.0' KETs (IoT, Big Data Analytics, Cloud Computing Services, Advanced Automation, Advanced HMI, Additive Manufacturing).	High level of specialization in the '4.0' KETs (especially IoT solutions applied to health care, environmental sustainability and retail and industry).

[241] For further information visit: "http://www.polomeccatronica.it/en/news/smart-cities-smart-forests-trentino-leading-revolution"

Advantages	Automatic data collection and sharing of information; environmental monitoring; more efficient and higher flexibility production processes.	Automatic data collection and sharing of information and traceability of products; more efficient and flexible production processes.	Automatic data collection and sharing of information; environmental monitoring.	Self-monitoring in the health care sector; monitor of hives and gather data concerning bees' behaviours in the agriculture sector; monitor buying behaviours of consumers and of employees in order to improve the organizational efficiency.
Obstacles	Need to upgrade internal competences to manage the shift.	Need for infrastructures to manage Big Data Analytics (Cyber-security); Family-managed companies (resistant to change); more support from the system (University and government).	Lack of domestic demand; need to upgrade skills.	Develop an internal market; need to face the final users' technological barriers.
Challenges	Adoption of SCM or advanced software for business analytics.	Define a clear strategy to face change.	Overcome the SMEs digital divide.	Develop the internal market.

Source: author's elaboration

Table 52: PPPs as effective tools of a mission-oriented innovation policy approach

Mission	PPP	Partners
Provide the citizens with an integrated channel for health services.	TreC	Province, Informatica Trentina, FBK, University of Trento, University of Venice, the consortium of Trentino municipalities, local professional associations of doctors and nurses, a local ICT company, 'GPI'.
	Co-innovation Lab on Big Data Analytics	Dedagroup, FBK.
Digitalize Trentino's forests.	Smart Forest	Trilogis, an ICT company based inside Polo Meccatronica, the Consortium of Trentino's municipalities, FEM and FBK.

Create an integrated platform for accelerating firms' digitalization and adoption of 'advanced manufacturing' technologies.	Prom-facility Lab	Trentino Sviluppo, FBK, the University of Trento and Confindustria Trento.

Source: author's elaboration

4.3.3. A top-down approach to innovation policy: a comparison with the national framework and some final remarks

RQ 4: Is a top-down approach to innovation policy sufficient to trigger the cross-level synergies between the players of a RIS which can positively influence the local technological development, thus favouring the socio-technical transition towards 'Industry 4.0'?

It may be interesting to discuss the results of the case study in light of the analysis performed at national level, tracing some implications concerning the importance of defining strategic innovation policies in the current socio-technical transition towards 'Industry 4.0'.

The analysis of the Italian NIS has suggested that a prevalently bottom-up/market-driven approach to innovation policy, based on horizontal and fragmented measures is associated to a substantial under-performance of the system in terms of some relevant innovation and technology indicators, especially related to high-tech activities, and it terms of the system's level of digitalization. In addition, also the propensity of firms to activate strategic PPPs for innovation activities has shown to be relatively low and prevalently concentrated in the high-tech manufacturing sector, where there is a significant influence of foreign multinationals; the system, despite the solid manufacturing industry and the highly attractive public research system, has a weak capacity to effectively stimulate virtuous interactions between the relevant players of the system; many academics attribute this weakness to a 'copious evidence of policy failure' (Virgillito and Romano, 2014; Lucchese et al. 2016).

The case of Trento partially differentiates from the national context, both in terms of innovation and technology performance and in terms of approach to innovation policy.

First of all, Trento shows a better performance in terms of some main innovation and technology indicators, with a relatively higher level of R&D expenditure on GDP, closer to the European rate, even if still suffering, like the country as a whole, of an overinvestment from the public sector and an underinvestment from the private sector; moreover, Trento performs better than the Italian country in terms of some other relevant indicators accounting for innovation activities (total R&D employees, graduated students in scientific and mathematical disciplines and the system's level of digitalization) and presence of highly innovative start-ups and SMEs (COTEC, 2016; CERVED, 2016).

Second, the Province shows a relatively higher vocation towards high-tech activities, given the high concentration of firms in the high-tech manufacturing and KIS sectors, with a relatively weak development of the manufacturing industry.

Third, the pattern of firms collaborating with Universities and research centres partially reflects the trends analyzed in the case of Italy, with some interesting elements of differentiation (summarized in Table 53 here below).

Whereas the sector's technological intensity has confirmed to be an important factor explaining firms' propensity to collaborate with other firms and institutions, there is also a relatively high propensity of firms in the low-tech and less KIS sectors, especially in the agrifood sector, cooperating with Universities and, particularly, with the local public research centres. These partnerships involve especially the innovation projects related to process innovations, in line with the work of Belderbos et al. (2006) and Freel and Harrison (2006), for which cooperation with Universities is generally more beneficial for process innovations rather than for product innovations.

Size has confirmed to be an important factor explaining firms' propensity to cooperate but there is also a relatively high propensity of micro, small and medium firms, which develop research partnerships with Universities and public research centres. Also belonging to a group of firms has confirmed to be an important factor, but in the end, it is firms' level of absorptive capacity, measured in terms of R&D intensity, presence of an innovation-oriented business strategy and employees' level of education, to be the most important factor explaining this propensity, more than size and sector.

Likewise, the access to public funds has confirmed to be an important incentive, but not the primary reason driving these firms to develop research partnerships, also because the access to fiscal incentives is more and more complicated by the highly bureaucratic procedures, which are bringing firms to prefer private sources of funding.

The major added value that firms recognize in the public action is related to its capacity to activate on the territory a system of coordinated and efficient players which play a crucial role as a source of attraction of new businesses from outside. The capacity to develop a system of proactive public research centres, Universities, innovation agencies and educational institutes, is strictly related to the system's strong institutional setting, which has been able to orient the Province towards a development trajectory based on research and innovation, which today reveal to be important sources of competitive advantage in the current technological scenario; this approach to policy making, based on both top-down and bottom-up measures, has been able to trigger the necessary cross-level synergies between the players of the RIS positively influencing the local technological development and thus the socio-technical transition towards 'Industry 4.0', as shown by the numerous examples of dynamic companies and by the network of local multi-scalar organizations highly specialized in this field.

However, the crucial condition for this approach to policy making to be effective is the adequate level of absorptive capacity of the system, which needs time to adapt during socio-technical transitions (Geels, 2005), requiring to be constantly improved; as stated in RIM (2016, p. 8): "Trentino's aspiration to be internationally recognised as a pioneer of the 'new industrial revolution' requires a constant effort to equip its economy and society for reaching this goal and for maintaining a position in the high ranks" (RIM, 2016, p.8).

Table 53: Propensity of firms to cooperate with Universities and public research centres: a comparison between the CIS (2010-2012) and the regional case study.

	The results of the CIS (2010-2012) analysis	The results of the regional case study
Sector	There is a positive correlation between firms' technological intensity and firms' propensity to collaborate with other firms and institutions.	Whereas firms' technological intensity has confirmed to be important, there is also a relatively high propensity of firms in the low-tech and less KIS sectors cooperating with Universities, especially with the local public research centres. What matters most is firms' level of absorptive capacity.
Size	There is a positive correlation between firms' size and firms' propensity to collaborate with other firms and institutions.	Whereas size has confirmed to be important, there is also a relatively high propensity of micro, small and medium firms to cooperate with Universities and especially with public research centres. Again, what matters most is firms' level of absorptive capacity.
Domestic/Foreign Group	There is a positive correlation between firms' belonging to a domestic/foreign group and firms' propensity to collaborate with other firms and institutions.	Firms which belong to a domestic group of firms cooperate more with Universities and public research centres, thanks to the possibility to get advantage of a larger network of companies.
Level of absorptive capacity	There is a positive correlation between firms' level of absorptive capacity and firms' propensity to collaborate with other firms and institutions.	The level of absorptive capacity (in terms of R&D intensity, business strategy and employees' level of education) has revealed to be the factor which counts most in explaining the propensity of firms to develop research partnerships, more than size and sector.
Public Funding	There is a positive correlation between firms' reception of local, national and European funds and firms' propensity to collaborate with other firms and institutions.	The access to public funds has confirmed to be an important incentive, but not the primary reason driving firms to develop partnerships, also because of the bureaucratic procedures. Companies are moving to more private sources of funding, like accelerators. What counts most is the possibility to have access to a system of coordinated and efficient players (Universities, research centres, public agencies and educational and training institutes).

Source: author's elaboration

5. Chapter Five: Conclusions

1. Basic steps of the research and main conclusion

The scope of the present Thesis was to understand how the strategic coordination between public and private players may represent an opportunity for the definition of effective innovation policies in the context of the current socio-technical transition, which I have referred to as 'Industry 4.0'. In order to reach this aim, a multilevel approach (Geels 2005) has been adopted, taking into account the micro, meso and macro levels of analysis and considering both the national and the regional dimensions.

First of all, I performed a quantitative analysis at national level with the purpose to understand whether a prevalently bottom-up/market-driven approach to innovation policy is able to adequately stimulate the innovation and technology performance and the level of firms' cooperativeness of the Italian country. The analysis has been made considering some relevant indicators accounting for Science, Innovation and Technology for Italy and other main European countries, and analysing the features of the innovative Italian firms derived from the CIS 2010-2012 dataset. Moreover, I have tested the statistical significance of some main variables at industry and firm levels explaining the propensity of firms to get involved in PPPs using a simple logistic model and providing a possible way to correct for endogeneity of some of the variables involved.

Second, I have conducted a field research at regional level, with the purpose to understand whether a top-down/institutional driven approach to innovation policy facilitates technological development in a RIS: Trento. Trento's case study has been the result of 57 semi-structured interviews to the local institutions and firms aimed at understanding their approach to 'Industry 4.0' and the challenges they are facing in this rapidly evolving technological scenario.

Overall, the Thesis, through the multiple sources of literature analyzed and the empirical analyses performed, leads to one main conclusion.

The complexity of the challenges posed by the so-called 'fourth industrial revolution' calls for a serious rethinking of effective innovation policies, which need to overcome the dualism between a 'top-down/picking the winner approach' and a 'bottom-up/market driven vision', which has dominated the industrial policy debate during the last decades (Forum, 2015). A mission-oriented approach to policy making (Mazzucato, 2014; European Commission, 2018) in which the public actor does not limit to fix the market or systems' failures, but identifies strategic societal problems, activating bottom-up solutions through strategic PPPs, provides a useful guidance in the current socio-technical shift. In fact, given the systemic nature of this techno-economic transition (Perez, 2010), characterized by deep techno-innovation, techno-economic asymmetries, and given the 'imperfect information' characterizing both the 'market' and the 'government' (Rodrik, 2004; 2014), only a symbiotic and vital cooperation between the private and public sectors may be able to activate the necessary cross-level synergies between the different players at different levels in order for the multiple challenges of this 'fourth-industrial revolution' to be successfully managed.

2. Detailed conclusions

Chapter Two has provided a broad literature review on the topics addressed in the present Thesis, analyzing the features of the new technological paradigm so called 'Industry 4.0', focusing on the origins, definitions and main concepts related to this term, the impact on the economy and the new business models; moreover, the Chapter addresses the need for effective innovation policies able to guide these transformations.

'Industry 4.0' was originally the name of the strategic plan introduced by the German government in 2011 (Acatech, 2011; 2013) containing a set of recommendations for the development of Germany's international position in industrial manufacturing through the promotion of digital structural change; today, the term has entered the common language of policy makers, practitioners, academics and business managers, to indicate an emerging industrial paradigm, which has its linchpin in the CPS: they make it possible the complete integration between the physical and the cyber space, generating a 'physical-digital Multiverse' (Lombardi, 2017). CPS are the basis of a number of KETs, both related to the 'software' and to the 'hardware' dimensions of the value chain organization: 'Industrial Internet of Things', 'Manufacturing Big Data Analytics', 'Cloud Manufacturing', 'Advanced Automation', 'Advanced HMI', 'Additive Manufacturing' (Osservatorio Smart Manufacturing, 2015). A broader definition of Industry 4.0 takes into account also renewable energy technologies, advanced materials and the next generation genomics, producing disruptive transformations in a wider range of contexts, from the utilities to the pharmaceutical and biological realm.

The combination of these technologies is producing radical changes in the economy (Schwab, 2016). The study of the growth dynamics must take into account the critical relationship between advanced automation and digitalization and productivity, the so-called 'productivity paradox', the fact that, despite the exponential growth in technological progress and investments in digital technologies, productivity, whether measured as 'labour productivity' or 'total factor productivity', has not increased at the same pace. Moreover, important changes concern the impact of advanced automation and digitalization on employment: whether there will be a 'destruction' or 'capitalization' effect, it is still matter of animated debate; however, the next century will be characterized for sure by the introduction of completely new occupations, especially related to high-income cognitive and creative jobs in the computer, mathematical, architecture and engineering fields (Frey and Osborne, 2017). An important phenomenon linked to the increasing automation of the business processes is also re-shoring and near-shoring (Fratocchi et al., 2016; Bailey and De Propris, 2014) for which many industrialized countries, like the U.S. for example, are bringing back the manufacturing activities in the native countries, being able to manage through advanced automation the more repetitive and routine phases of the value chain.

In this context, also the business models are going through deep changes (McKinsey, 2016): we are assisting at the progressive 'servitisation' of the economy, where products are inseparable from the service they incorporate and become *multi-technology*, as a result of the combination of a variety of technological domains, from mechanics, electronics and software to mathematics and physics. “The innovative dynamics are radically changing: it is not longer convenient to specialize in the sector you are good at, but, precisely because you are good in that sector, you must explore others” (Federica Dallanoce, ADACI, Fabbrica Futuro, 8th June 2016, Bologne). Businesses are increasingly finding convenient to adopt a ‘collaborative’ and ‘open innovation model approach’ (Chesbrough, 2003) through digital ecosystems, playing an important role in a variety of different contexts, from manufacturing, logistics services, energy services to farming and health care, and questioning the traditional significance of companies’ and sectors’ traditional boundaries (Lombardi, 2017).

The review of the policy approaches adopted by the global industrial powers (PCAST, 2011; 2014; European Parliament, 2015; Acatech, 2013; 2015; VDMA, 2015; TSB, 2012; X Commissione Permanente, 2016) has shown that strategic PPPs are at the basis of these countries’ industrial strategies, based on a combination between both top-down and bottom-up measures, aimed at accelerating the shift towards ‘Industry 4.0’ or ‘advanced manufacturing’ (Lombardi, 2017).

The analysis of the economic approaches to policy-making from a theoretical point of view has substantially confirmed this evolving trend: the recognition of innovation as a ‘complex’ and not ‘linear’ process, resulting from the interaction of heterogeneous and bounded rational players has signed the shift from a neoclassical approach to policy making based on market failures (Arrow, 1962; Romer, 1986; Swann, 2009; 2010) to an evolutionary framework of the systems of innovation (Cooke et al., 1997; Cooke, 1998; Cooke, 2001; Asheim and Isaksen, 2002; Balzat and Hanusch, 2003; Breschi and Malerba, 1997; Carlsson and Stankiewicz, 1991; Edquist, 2004; Freeman, 1995; 1987; Lundvall, 1988; 1992, 2005; Metcalfe, 2005; Uyarra, 2011; Dodgson et al. 2010) and complexity theories (Cantner et al, 2010; Arthur, 2009; Frenken, 2006; Hirooka, 2006). Despite the significant progresses made by the ‘systemic’ and ‘complexity’ approaches towards a better comprehension of how innovation processes work, a new theoretical paradigm for policy making in which the public actor implements innovation-led industrial strategies in a dynamic relationships with the private actor still needs to be properly built.

This is precisely the ambition of the new emerging approach to innovation policy making, the mission-oriented approach (Mazzucato, 2014; Mazzucato and Perez, 2014; European Commission, 2018; Frenken, 2017), which proposes itself as an alternative to the two prevailing theories characterizing the decades after the Second World War: the ‘picking the winner approach’, related to the strong governmental intervention aimed at reconstructing the economy (1950s-1980s) and the of neo-liberal policies (1980s-2000), based on the idea of a ‘self regulating market’. This approach aims at overcoming the old ‘State vs. market’ ideological opposition supporting a strategic dialogue between the two sides through a combination of both top-down and bottom-up measures. “Rather than focusing on particular sectors - as in traditional industrial policy - mission-oriented policy focuses on problem-specific societal challenges, which many different sectors interact to solve (...). It is not enough to fix market and system failures: policy-makers need to be more future focused, creating and shaping new markets”. “The right way of thinking of industrial policy is as a discovery process-one where firms and the government learn about underlying costs and opportunities and engage in strategic coordination. (...) What is needed (...) is a more flexible form of strategic collaboration between public and private sectors, designed to elicit information about objectives, distribute responsibilities for solutions, and evaluate outcomes as they appear” (Rodrik, 2004, pp. 19).

This is true especially during socio-technical transition phases (Geels, 2002; 2004; Perez, 2001; 2009; 2010) characterized by techno-innovation and techno-economic discontinuities, where each of the players involved are limited by knowledge asymmetries: whereas the market or the system failure approach can provide a useful guidance when the system is in a steady state, only a strategic cooperation between public and private players would be able to manage disequilibrium phases (Mazzucato, 2014). Three principles are suggested in order for PPPs to be effective policy instruments (Rodrik, 2014): *embeddedness*, that is the need for neither the public sector nor the private sector to operate autonomously but to strategically interact, learning where the bottlenecks are and how best to pursue the opportunities; *discipline*, that is the need to adopt discipline devices against firms gaming the system; *accountability*, that is the need to keep transparency in both their activities in order to gain legitimacy.

The empirical analyses provide evidence both at national and at regional levels, of the crucial role of the public actor in adopting a strategic approach to innovation policy able to reach adequate levels of innovation and technology performance.

The analysis at national level has shown that a prevalently bottom-up/market-driven approach to innovation policy, based on the substantial lack of the strategic action of the public actor in innovation is associated to a relatively weak innovation and technology performance; moreover, the firms reveal to have a relatively low propensity to develop collaborative innovation projects.

Moreover, in line with the overview of the main empirical studies on the topic, the logit analyses performed in order to assess the Italian firms’ propensity to be involved in PPPs, have revealed that the variables at industry level (the sector and the industry’s R&D intensity), at firm’s level (the size, belonging to a domestic of foreign group of enterprise, having a high level of innovativeness and absorptive capacity) and at national level (the reception of public funds) are the main drivers explaining firms’ propensity to be involved in cooperative agreements for innovation activities. As shown in the work of Segarra-Blasco and Arauzo-Carod (2008), firms' technological intensity is a key factor explaining firms’ propensity to innovate and to get involved in PPPs.

The Italian firms’ relatively low propensity to invest in R&D activities and to cooperate with other firms and institutions seriously questions the country’s governmental innovation and technology policy approach adopted so far, especially considering the complex challenges posed by the rapidly changing technology landscape, where innovation is more and more the result of a complex interaction process between players at different levels. The presence of a solid manufacturing-based industry and a high-quality public research system represent two important strengths in this scenario, which could be properly enhanced through a more innovation-led governmental policy stimulating effectively public-private symbiotic and synergic interactions.

The analysis at regional level has suggested that a top-down/institutional approach to innovation policy has been able to positively influence the innovation and technological performance at local level. The local institutions have revealed to be crucial players able to enhance the innovative potential and the economic renewal of the region: the relatively disadvantageous orographic conditions of the local territory have not represented obstacles for the emergence and development of a system based on research and innovation, thanks to the strong institutional nature of the RIS, in line with similar results in the literature (Doloreux and Dionne, 2008). The 'institutional thickness' of the system (Trippl et al. 2015a) is nurtured by the presence of a network of multi-scalar organizations which have been able to attract extra-local knowledge flows, making it possible for the system to enter the circuits of national and international knowledge. Also thanks to the influence of important non-local flows of knowledge, the industry is going through a 'path renewal' process (Isaksen and Trippl, 2014; Trippl et al., 2015b) visible in the development of the prestigious technological hubs like 'Polo Meccatronica' and 'Progetto Manifattura', in the mechatronics and renewable energies sectors, which are strategic sectors in the current technological scenario which are attracting many key national players from outside, especially research centres of big multinationals.

In this respect, the Province, which share some elements of a 'mission-oriented' approach to policy making, based on the adoption of both top-down and bottom-up measures, counts a number of interesting local PPPs which are shown to be effective policy instruments able to translate at local level the knowledge inputs of this multi-scalar framework, increasing the overall innovative potential of the RIS: TreC, the local digitalized citizen health record, the co-innovation lab for the improvement of big data analytics, the smart forests project and the Prom Facility Lab inside Polo Meccatronica bring together the public actor, the research centres and the local companies in order to share competences and knowledge raising the system's technological development and overall innovative potential (Kristensen and Scherrer, 2016; Fogelberg and Thorpenberg, 2012; Wieczorek and Hekkert 2012). These instruments support the Province in facing one of the most significant challenges questioning the system's competitive advantage: the improvement of the impact at local level of the extremely high level of sophistication reached by the players of the 'knowledge creation subsystem' (research centres, Universities, public agencies), which is hindering the system's full innovation potential.

The set of institutional and organizational features of this regional system makes Trento particularly interesting in the context of the debate on 'Industry 4.0'. Today the local research centres, in particular FBK, play a strategic role in this scenario, being specialized in a number of knowledge domains linked both to the 'hardware' and 'software' dimensions of the 'Industry 4.0' paradigm. Although the majority of the projects both in the CMM and the ICT centres are usually developed in the context of partnerships with the European Commission, the centre counts also some important R&D projects with strategic partners, in the industrial, biomedical, aerospace and utility sectors. However, the impact on the local territory is still a critical issue, partially due to the highly sophisticated technologies they offer and to the relatively low absorptive capacity of the local enterprises.

The approach to 'Industry 4.0' of the local companies interviewed revealed some interesting points. Regardless of the sector, each firm interviewed, with some exceptions, has shown to be familiar with the 'Industry 4.0' technologies, recognizing the high potential of digitalization and automation in terms of higher efficiency, flexibility and increase in the products' quality.

Specifically, the firms in the agrifood sector have upgraded their technological competences thanks to many innovative projects with the local research centres, especially FBK and FEM, and to ex-spinoff companies in the ICT sector which supported them in the adoption of integrated platforms for the 'smart management' of their vineyards and sensor projects for the measurement of the fruits' level of maturity.

In mechatronics, the level of firms' absorptive capacity is the main factor explaining the propensity to adopt the 'Industry 4.0 KETs'. The group of more 'traditional' companies is characterized by a strong latent potential in the usage of these technologies, which, however, is hindered by the lack of a precise strategy able to face changes, due to a closed mental attitude, often linked to a family-owned approach, the lack of an adequate internal organizational structure, the lack of systemic interactions with the other players of the innovation system. On the contrary, the group of 'innovative' companies shows a high level of specialization in the 'Industry 4.0' technologies, being ex-spinoff from research centres or companies with a research background in advanced engineering; they are usually involved in innovation projects with Universities and research centres and have a collaborative approach with the local institutions and the other players of the system. Finally, the companies in the ICT sector have revealed the extremely high potential of the 'Internet of Things' in different sectors, from health-care and environmental sustainability to retail and industry.

Regardless of the sector, each firm indicated some main advantages and obstacles linked to the adoption of these technologies. The main advantages concern the possibility to perform automatic data collection and sharing of information able to monitor data in a variety of contexts, from health care, to mechanical to agriculture and industry and retail sectors, realizing substantial improvements in the efficiency and flexibility of their business processes; the main obstacles are the need to improve the approach of local Universities and research centres in terms of a higher proactiveness on the local territory, the lack of a domestic demand able to 'absorb' the sophisticated technologies they produce, the final users' technological barrier (for ICT companies), and the need to upgrade their employees' digital competences and skills in order to manage the shift. In this respect, Trento's educational system seems to be up to this important challenge, with technical institutes collaborating with the local enterprises and with Polo Meccatronica in the definition of integrated curriculum between different knowledge domains, which in the past were treated as separated disciplines, mechanics, electronics and information technologies; they are aware that, in order to be able to face the current technological challenges, only a cross-fertilization approach must be followed.

The four large and medium companies in ICT, advanced materials, advanced engineering and renewable energies, selected as business case studies, confirmed the importance to develop a strategic public-private coordination to manage this shift; they highlighted the need to develop partnerships with SMEs in order to reduce the digital divide, the need to manage big data analytics in order to reduce the level of 'unpredictability' of the working conditions, the need to manage the structural change in the economy and in the labour market, through a 'systemic' approach, rather than through 'thinking in silos' (Schwab, 2016; Lombardi, 2017), and the crucial importance to adopt a multidisciplinary approach to competence exchange.

Lastly, in light of the analysis performed on the data of the CIS 2010-2012 at national level, the pattern of firms collaborating with Universities and research centres partially reflects the trends analyzed in the case of Italy, with some interesting elements of differentiation. The firms' level of absorptive capacity, measured in terms of R&D intensity, the presence of an innovation-oriented business strategy and employees' level of education, has revealed to be the most important factor explaining this trend, more than any other factor, like size and sector. In fact, whereas the sector's technological intensity has confirmed to be important in explaining firms' propensity to collaborate with other firms and institutions, there is also a relatively high propensity of firms in the low-tech and less KIS sectors, especially in the agrifood sector, cooperating with Universities and especially with the local public research centres, thanks to the efficient system of coordinated players, which locally activates virtuous synergies among the public and private players. Size has confirmed to be an important factor explaining firms' propensity to cooperate, but there is also a relatively high propensity of micro, small and medium firms to develop research partnerships with Universities and public research centres. Finally, the access to public fund has confirmed to be an important incentive, but not the primary reason driving these firms to develop research partnerships, also because the access to fiscal incentives is difficult due the highly bureaucratic procedures which are bringing firms to prefer private sources of funding; the major added value that firms recognize in the public action is related to the capacity to activate on the territory a system of coordinated players of high quality, playing a crucial role as a source of attraction of new businesses from outside.

The capacity to develop a system of proactive public research centres, Universities and innovation agencies and educational institutes, is strictly related to its strong institutional setting and to the presence of a strategic 'top-down' approach to policy making, which has been able to orient the Province towards a development trajectory based on research and innovation, which today reveal to be important sources of competitive advantage in the context of the current technological scenario; this approach has been able to trigger the necessary cross-level synergies between the players of the RIS positively influencing the local technological development and thus favouring the socio-technical transition towards Industry 4.0. However, the crucial condition for which this approach reveals to be effective is represented by the adequate level of absorptive capacity of the system, which usually takes time to adapt during socio-technical transitions (Geels, 2005).

Overall, both the analyses performed at national and regional levels suggest the need to adopt new lenses of analysis for the study of the innovation processes; the theoretical concepts of national and regional innovation systems, usually adopted as categories in the innovation literature, must evolve in order to deal with the current technological scenario. In this context, the integration between the 'physical' and the 'virtual' dimensions is widening exponentially the global connectivity space, thus questioning the significance of the 'territorial' dimensions of innovation systems. These categories, which have represented the traditional frameworks for the analysis of the innovation processes must be revised in order to take into account the fundamental role played by the sub-system of global networks based on research centres, public organizations and global players which act as catalyzing agents, through the constant combination of the 'global' and the 'local' dimensions (Randelli and Lombardi, 2014), as the virtuous example of the FBK centre of scientific excellence has shown. This constitutes the first important line of research to be further developed.

Moreover, there are other possible research avenues which can be addressed.

First, the quantitative analysis on the Italian NIS has been limited to the understanding of the relationship between a specific approach to innovation policy, the overall innovation and technology performance and the level of diffusion of PPPs in a NIS characterized by a prevalently bottom-up/market-driven approach to industrial policies; it could be interesting to enrich the analysis using a comparative framework, taking into account countries characterized by a different institutional setting and approach to innovation and technology policies, like Germany, France and UK. Moreover, the analysis performed on the CIS 2010-2012 data was limited to the understanding of the determinants at firm and industry level explaining firms' involvement in cooperative agreements with other firms and institutions for the Italian country. Given the growing importance of PPPs as tools of innovation policy, it could be interesting to extend the analysis, estimating the impact of firms' participation to cooperative innovation projects on firms' product and process innovations, in line with recent contributions in this direction (Robin and Schubert, 2013; Schøtt and Jensen, 2016). Finally, it could be interesting to go on further estimating the results of the Generalized Structural Equation Modelling (GSEM) approach introduced in Appendix 1a, in order to compare the results obtained with the ones derived from the probit model, in order to comprehend how the problem of endogeneity of some of the variables involved may be managed.

Second, the qualitative study on the case of Trento's RIS has been aimed at analyzing the level of technological development of a system with specific organizational and institutional features, institutional thickness and organizational thinness (Trippl et al. 2015a). It could be interesting to extend the analysis to other Italian regions with different institutional and organizational features, like Emilia Romagna, Tuscany and Lombardy, characterized instead by solid manufacturing systems but different institutional settings, in order to better understand how different institutional/organizational settings may influence local technological development, positively favouring the shift towards 'Industry 4.0'. Moreover, the study of the level of knowledge and usage of the 'Industry 4.0' KETs by the Italian enterprises has been limited to a relatively small sample of companies chosen randomly among different macro sectors: it could be interesting to develop the analysis taking into account a larger sample at national level, in order to better understand the transformative potential of these technologies for the whole industry.

APPENDIX

Appendix 1a

As also Leoncini (2016) reminds us, the CIS dataset is a cross section, which inevitably implies problems of endogeneity and reverse causality. In fact, while it is true that firms' propensity to cooperate during 2010-2012 may depend on firms' level of innovativeness, it may also be that the cooperation with other firms and institutions influences firms' innovativeness. A possible way to mitigate the problem of endogeneity of some of the variables involved is using an instrumental variable approach, which is the standard method to manage endogeneity (Wooldridge, 2010). However, as also Lòpez (2008) highlights, it is difficult to find perfectly exogenous instruments within the CIS, since every question is closely related and cross-section data are used. A possible solution to attenuate the problem is taking advantge of the fact that on the file of anonymized data, data related to firms' expenditure for innovation activities in 2012 have been changed to the share of the expenditure in 2010 on total turnover in 2010, in order to protect firms' confidential information. Since data are referred to a period which is prior to the development of a cooperative agreement, the instruments may mitigate the endogeneity of the variables chosen.

As already mentioned, among the variables used, I identified three endogenous variables representing firms' innovative capacity: developing product and process innovations during 2010-2012, performing intramural R&D activities during 2010-2012 and performing external R&D activities during 2010-2012. For each endogenous variable, I selected specific instruments: the introduction of both product and process innovations between 2010-2012 may be instrumented by the mean of the total expenditure for innovation activities in 2010 on total turnover in 2010, by industry (rallmean); intramural R&D activities between 2010-2012 may be instrumented by the mean of firm's expenditure for internal R&D activities in 2010 on total turnover in 2010, by industry (rrdinxmean); external R&D activities between 2010-2012 may be instrumented by the mean of the expenditure for external R&D activities in 2010 on total turnover in 2010, by industry (rrdexxmean).

The probability that firm *i* cooperates with other firms and institutions (or with other partners involved) is specified using a probit model. In a second step, I will consider an instrumental variable approach to mitigate for endogeneity.

The probability model for cooperation of firm *i* with other firms and institutions can be derived considering a continuous unobserved response y_i^* representing the attitude of the firm to cooperation, $y_i^* = \mathbf{x}_i'\boldsymbol{\beta} + \mathbf{w}_i'\boldsymbol{\gamma} + \varepsilon_i$, with errors $\varepsilon_i \sim N(0, \sigma^2)$, and $y_i = \mathrm{I}(y_i^* \geq 0)$, with I(.) indicator function, i.e. $y_i = 1 \; if \; y_i^* \geq 0$, and zero otherwise.

Thus, the probability that firm *i* cooperates with other firms and institutions is given by the following probit model:

$$\mathrm{P}(y_i = 1|\mathbf{X}, \mathbf{W}) = \Phi(\mathbf{x}_i'\boldsymbol{\beta} + \mathbf{w}_i'\boldsymbol{\gamma})(1)$$

where y_i is the observed binary response representing whether firm *i* has cooperated with other partners or not during 2010-2012, $\Phi(.)$ is the standard Normal cumulative function, $\boldsymbol{\beta}$ is the vector of parameters $\boldsymbol{\beta}$'=(β_0, β_1, ... β_k), including the constant term β_0, $\mathbf{x}_i'$ is the (k+1) vector of exogenous covariates $\mathbf{x}_i' = (1, x_{1i}, ..., x_{ki})$ and $\mathbf{w}_i' = (w_{1i}, ..., w_{qi})$ is the vector of (possibly) endogenous covariates.

If one or more covariates, like in our case, are endogenous, the maximum likelihood estimators are inconsistent (Wooldridge, 2010). To solve this problem, I rely on the eprobit command of Stata (2015), implementing a maximum likelihood estimator (see chapter 13 of Wooldridge, 2010).

As already mentioned, in our case, we have three endogenous binary covariates: having introduced both product and process innovation during 2010-2012, having performed intramural R&D activities during 2010-2012 and having performed external R&D activities during 2010-2012. Since the endogenous covariates are binary, indicator (dummy) variables $w_{ij}$for the levels of each binary covariate are used in the model, $j = 1,2,3$. We specify a probit model for each binary endogenous covariate:

$$P(w_{ij} = 1) = \Phi(\mathbf{z}_{ij}'\boldsymbol{\delta}_j)$$

where w_{ij} is the observed counterpart of a continuous unobserved covariate, i.e. $w_{ij} = \mathrm{I}(\mathbf{z}_{ij}'\boldsymbol{\delta}_j + \nu_{ij} \geq 0)$. The errors $\nu_{i1}, \ldots, \nu_{iJ}$ are multivariate normal with mean 0 and covariance matrix Σ_w, with variances fixed to one and non-null correlations. The outcome error ε_i and binary endogenous errors ν_{ij} are multivariate normal (see Stata, 2015 for more details).

In order to compute the Average Marginal Effects (AMEs) of the probit model taking into account the endogeneity of some variables, I used the *eprobit* command available in the Stata software version 15.0, which fits a probit regression model that accommodates any type of endogenous covariates, including the binary, as in our case.

Table 54 here below shows the AMEs of the probit model, without taking into account endogeneity, and Table 55 and Table 56 show, respectively, the coefficients and the AMEs of the probit model taking into account endogeneity[242].

First of all, Table 55 shows that the instruments chosen, the mean of the share of investments in innovation activities on firm's turnover in 2010 by industry for "having introduced both product and process innovations" and the share of investments in internal R&D activities on firm's turnover in 2010 by industry

[242] In this preliminary stage, to simplify the model estimations, I took into account only two out of three endogenous variables, having introduced product and process innovations during 2010-2012, and having performed internal R&D activities during 2010-2012. Further work is needed to refine the results taking into account also the third endogenous variable, having performed external R&D activities during 2010-2012.

for "having performed internal R&D activities in 2010-2012", seem to be acceptable, since the coefficients are statistically significant at 1% level.

Moreover, a preliminary comparison between the AMEs of the probit model considering or not these variables as endogenous suggests that endogeneity partially affects the results: the major changes concern the AMEs of the instrumented variables, having introduced both product and process innovations and having performed intramural R&D activities.

Concerning the industry variables, belonging to a high-tech manufacturing sector is positively correlated with the probability of being involved in a cooperative agreement with group firms, clients and suppliers and Universities and this result is confirmed when taking into account the endogeneity of the variables involved; belonging to a KIS is positively correlated with the probability of being involved in cooperative agreements with each player taken into account (statistically significant at 1%), except for clients and suppliers, while, when taking into account endogeneity, the correlation is statistically significant also for clients and suppliers. The industry average investments in innovation activities is positively correlated with the probability to cooperate with Universities (significant at 1%) and it turns to be statistically significant also for public research centres (significant at 1%) and clients and suppliers (significant at 5%), when taking into account endogeneity.

As for the firm variables, the large size is confirmed to be a highly statistically significant variable in both cases, except for the cooperation with clients and suppliers when taking into account endogeneity; moreover, belonging to a domestic group is positively correlated with the probability to cooperate with competitors, Universities and public research centres, and, when endogeneity is taken into account, with clients and suppliers, competitors and Universities; belonging to a foreign group, which results positively correlated with the probability to cooperate with public research centres, turns out to be positively correlated with the probability to cooperate only with Universities, when taking into account endogeneity.

The results of the probit model without taking into account endogeneity show that having introduced both product and process innovations is positively correlated with the probability to cooperate with each player taken into account (highly significant at 1%), but when correcting for endogeneity, the results are statistically significant only for Universities, public research centres and clients and suppliers; the same result holds for having performed intramural R&D activities; investing more than the industry average in innovation activities results to be positively correlated the probability to cooperate with group firms, competitors and public research centres, and, when taking into account endogeneity, with group firms, clients and suppliers and competitors. The total expenditure in internal R&D activities in 2010/Turnover in 2010 by industry results to be negatively correlated with the probability of being involved in cooperation with clients and suppliers, competitors, Universities and public research centres, while it is positively correlated with the probability to cooperate with group firms. This result may be explained by the fact that firms performing internal R&D activities may be less inclined to develop partnerships with other companies, which are external from the group.

Finally, the reception of local and national public funds confirms to be positively correlated with the probability to cooperate with group firms, competitors, Universities and public research centres and this result holds also when taking into account endogeneity. The same result holds for the reception of European public funds: in both cases the probabilities are highly statistically significant for each player taken into account.

Table 54: Average marginal effects of the probit model without taking into account endogeneity

	All partners	**Group firms**	**Clients and Suppliers**	**Competitors**	**Universities**	**Public research centres**
	b/se	b/se	b/se	b/se	b/se	b/se
Industry variables						
High-tech	0.021	0.033**	0.012***	-0.007	0.029*	0.007
	(0.014)	(0.016)	(0.006)	(0.009)	(0.010)	(0.008)
KIS	0.086*	0.075*	0.007	0.042*	0.044*	0.046*
	(0.014)	(0.016)	(0.006)	(0.010)	(0.010)	(0.009)
Industry investments in innovation activities	0.690**	0.173	0.104	0.049	0.669*	0.170
	(0.338)	(0.363)	(0.131)	(0.200)	(0.202)	(0.146)
Firm variables						
Size (50-249)	-0.010	-0.003	0.002	-0.006	0.009	0.004
	(0.011)	(0.012)	(0.005)	(0.007)	(0.008)	(0.006)
Size (more than 250)	0.096*	0.097*	0.016**	0.027*	0.086*	0.031*
	(0.016)	(0.015)	(0.007)	(0.010)	(0.011)	(0.008)
Domestic Group	0.078*	.	0.008	0.019**	0.040*	0.017**
	(0.011)	.	(0.005)	(0.008)	(0.008)	(0.007)
Foreign Group	0.066*	.	0.011	-0.001	0.021	0.020***
	(0.019)	.	(0.009)	(0.011)	(0.013)	(0.011)
Deviation from Industry average investments in innovation activities	0.131**	0.201*	0.029	0.066**	0.020	0.051**
	(0.055)	(0.065)	(0.021)	(0.033)	(0.038)	(0.026)
Product and process innovations	0.078*	0.088*	0.021*	0.028*	0.035*	0.024*
	(0.010)	(0.012)	(0.004)	(0.007)	(0.007)	(0.005)
Innovation Source						
Intramural R&D	0.099*	0.038*	0.026*	0.035*	0.074*	0.033*
	(0.011)	(0.012)	(0.005)	(0.007)	(0.008)	(0.006)
Sources of Funds						
Local public funds	0.088*	0.032**	0.004	0.030*	0.067*	0.037*
	(0.013)	(0.015)	(0.005)	(0.009)	(0.010)	(0.008)
National public funds	0.068*	0.042**	0.006	0.021**	0.056*	0.053*
	(0.017)	(0.017)	(0.006)	(0.011)	(0.011)	(0.010)

European public funds	0.170*	0.129*	0.031*	0.110*	0.136*	0.099*
	(0.026)	(0.027)	(0.011)	(0.020)	(0.020)	(0.017)
N	6455	3553	6455	6455	6455	6455

Source: author's elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

Table 55: Coefficients of the probit model taking into account endogeneity

	All partners	**Group firms**	**Clients and Suppliers**	**Competitors**	**Universities**	**Public research centres**
Industry variables	b/se	b/se	b/se	b/se	b/se	b/se
High-tech	0.088	0.169**	0.054**	-0.061	0.056**	0.015
	(0.057)	(0.074)	(0.021)	(0.078)	(0.027)	(0.019)
KIS	0.324*	0.358*	0.032***	0.310*	0.053*	0.073*
	(0.069)	(0.072)	(0.017)	(0.069)	(0.019)	(0.018)
Industry investments in innovation activities	2.221	-2.713	5.320*	2.007	6.376*	6.328*
	(2.529)	(2.818)	(1.129)	(2.969)	(1.090)	(1.098)
Firm variables						
Size (50-249)	-0.044	-0.016	-0.001	-0.058	0.023***	0.022***
	(0.048)	(0.077)	(0.013)	(0.067)	(0.014)	(0.013)
Size (more than 250)	0.351*	0.461*	0.003	0.203*	0.193*	0.081*
	(0.075)	(0.077)	(0.020)	(0.075)	(0.028)	(0.020)
Domestic group	0.316*	-0.214*	0.036*	0.161**	0.051*	0.012
	(0.063)	(0.066)	(0.013)	(0.063)	(0.014)	(0.013)
Foreign group	0.252*	.	0.021	-0.012	0.047**	0.026
	(0.076)	.	(0.022)	(0.096)	(0.021)	(0.022)
Deviation from Industry average investments in innovation activities	0.549**	1.041*	0.124***	0.547***	0.047	0.086
	(0.236)	(0.340)	(0.074)	(0.280)	(0.089)	(0.092)
Product and Process innovations	-0.366	0.201	-1.738*	-0.052	-1.486*	-1.620*
	(0.819)	(0.599)	(0.037)	(0.654)	(0.029)	(0.033)
Innovation Sources						
Intramural R&D	0.670**	0.977*	-0.112*	0.075	0.134*	-0.113*
	(0.335)	(0.345)	(0.014)	(0.440)	(0.013)	(0.015)
Sources of funds						
Local funds	0.330*	0.156**	-0.002	0.231*	0.100*	0.070*
	(0.066)	(0.070)	(0.017)	(0.063)	(0.021)	(0.019)
National funds	0.254*	0.198*	0.017	0.165**	0.187*	0.156*
	(0.069)	(0.076)	(0.025)	(0.076)	(0.036)	(0.034)
European funds	0.575*	0.525*	0.094**	0.636*	0.478*	0.376*
	(0.112)	(0.100)	(0.038)	(0.095)	(0.053)	(0.055)
_cons	-1.475*	-1.870*	-0.369*	-1.862*	-0.476*	-0.394*

	(0.504)	(0.263)	(0.020)	(0.384)	(0.021)	(0.020)
Instrumented variables						
Product and Process innovations						
Industry investments in innovation activities	3.886*	3.775*	4.987*	3.884*	6.257*	5.931*
	(1.141)	(1.431)	(1.096)	(1.136)	(1.119)	(1.091)
_cons	-0.362*	-0.232*	-0.374*	-0.361*	-0.401*	-0.391*
	(0.019)	(0.026)	(0.019)	(0.019)	(0.019)	(0.019)
Intramural R&D						
Total expenditure in R&D activities in 2010/Turnover in 2010 by industry	11.125*	8.322*	11.392*	11.022*	11.417*	11.408*
	(1.072)	(1.144)	(1.102)	(1.065)	(1.103)	(1.100)
Model						
_cons	-0.429*	-0.205*	-0.433*	-0.429*	-0.433*	-0.433*
	(0.017)	(0.022)	(0.017)	(0.017)	(0.017)	(0.017)
N	6455	3553	6455	6455	6455	6455

Source: author's elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

Table 56: Average marginal effects of the probit model taking into account endogeneity

	All partners	**Group firms**	**Clients and Suppliers**	**Competitors**	**Universities**	**Public research centres**
	b/se	b/se	b/se	b/se	b/se	b/se
Industry variables						
High-tech	0.022	0.035**	0.015**	-0.007	0.023***	0.005
	(0.015)	(0.016)	(0.007)	(0.009)	(0.012)	(0.006)
KIS	0.085*	0.077*	0.008***	0.042*	0.021*	0.024*
	(0.014)	(0.016)	(0.005)	(0.010)	(0.008)	(0.007)
Industry investments in innovation activities	0.277	-0.603	0.294**	0.187	0.569**	0.494*
	(0.637)	(0.592)	(0.128)	(0.357)	(0.249)	(0.166)
Firm variables						
Size (50-249)	-0.010	-0.003	-0.000	-0.006	0.008	0.006
	(0.011)	(0.012)	(0.003)	(0.007)	(0.005)	(0.004)
Size (more than 250)	0.096*	0.098*	0.001	0.027*	0.088*	0.027*
	(0.016)	(0.015)	(0.005)	(0.010)	(0.014)	(0.008)
Domestic group	0.079*	.	0.009*	0.019**	0.019*	0.004
	(0.012)	.	(0.003)	(0.008)	(0.005)	(0.004)
Foreign Group	0.066*	.	0.005	-0.001	0.019**	0.008
	(0.019)	.	(0.006)	(0.011)	(0.009)	(0.007)

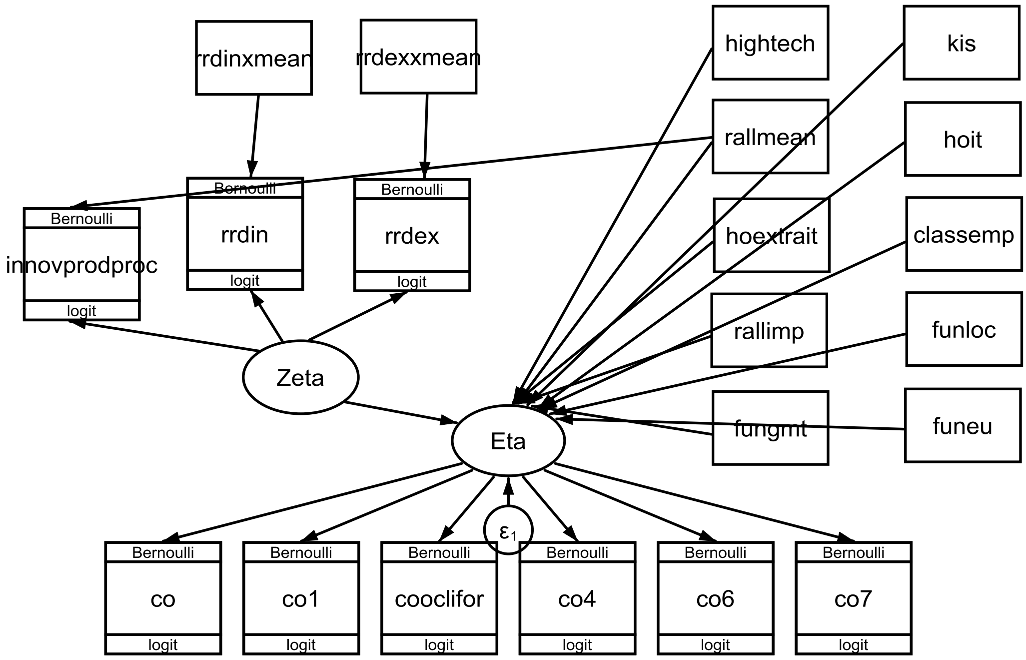
Deviation from Industry average investments in innovation activities	0.134**	0.204*	0.029***	0.065**	0.017	0.024
	(0.055)	(0.066)	(0.017)	(0.033)	(0.033)	(0.026)
Product and Process innovations	0.078	0.087	0.024*	0.028	0.033*	0.020*
	(0.206)	(0.125)	(0.005)	(0.080)	(0.008)	(0.006)
Innovation Sources						
Intramural R&D	0.098	0.038	0.027*	0.035	0.070*	0.036*
	(0.091)	(0.072)	(0.004)	(0.055)	(0.006)	(0.005)
Total expenditure in internal R&D activities in 2010/turnover in 2010 by industry	0.300*	0.490*	-0.254*	-0.106*	-0.076*	-0.319*
	(0.040)	(0.084)	(0.028)	(0.012)	(0.008)	(0.033)
Sources of funds						
Local funds	0.088*	0.032**	-0.001	0.030*	0.043*	0.024*
	(0.013)	(0.015)	(0.004)	(0.009)	(0.010)	(0.007)
National funds	0.068*	0.042**	0.004	0.021**	0.087*	0.062*
	(0.017)	(0.017)	(0.007)	(0.011)	(0.018)	(0.016)
European funds	0.170*	0.129*	0.031**	0.110*	0.244*	0.172*
	(0.027)	(0.028)	(0.015)	(0.020)	(0.029)	(0.028)
N	6455	3553	6455	6455	6455	6455

Source: author's elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

An alternative way to mitigate the problem of endogeneity of some of the variables involved in the initial logit model is using a Generalized Structural Equation Modelling Approach (GSEM), which is able to explicitly model both non-linearity and endogeneity simultaneously, avoiding the use of the traditional Instrumental Variable two-step procedure. GSEM models endogeneity through common unobserved components (see Rabe-Hesketh and Skrondal, 2012; Skrondal and Rabe-Hesketh, 2004). In particular, GSEM handles endogeneity by including common, unobserved components into the equations for different variables. A GSEM is generally described using a path diagram. Assuming that firms' propensity to cooperate with other partners and firms' level of innovativeness cannot be observed, latent variables may be added in order to take into account possible unobserved effects. Given *Eta* the latent variable representing firms' propensity to cooperate with other partners and *Zeta* the latent variable representing firms' level of innovativeness, the path diagram may be represented as in Figure 45.

The introduction of a latent variable makes it possible to take into account possible unobserved effects, including the possibility that firm *i* which did not cooperate during 2010-2012, was actually involved in cooperative agreements previously. In order to provide a comparison between the results of the Instrumental Variable approach and of the GSEM, it could be interesting to further calculate the estimations of the structural model. However, as also this model relies on the choice of perfectly exogenous instruments and since in the CIS it is very difficult to find perfectly exogenous instruments (Lòpez, 2008), in this stage of the research I prefer not to provide the estimations, which maybe a possible avenue for future research.

Figure 45: Path diagram of the GSEM with latent variables



Source: author’s elaboration

Appendix 1b

Table 57: Coefficients of the logit model for cooperation with other firms and institutions

	(1)	(2)	(3)	(4)	(5)
	All partners	**All partners**	**All partners**	**All partners**	**All partners**
	b/se	b/se	b/se	b/se	b/se
Industry variables					
High-tech	0.580*	0.409*	0.104	0.077	0.064
	(0.093)	(0.096)	(0.101)	(0.103)	(0.104)
KIS	0.485*	0.440*	0.518*	0.600*	0.627*
	(0.087)	(0.089)	(0.091)	(0.092)	(0.093)
Average industry investments in innovation activities	17.354*	17.293*	10.100*	6.564*	4.152***
	(2.214)	(2.261)	(2.382)	(2.435)	(2.506)
Firm variables					
Size (50-249)	0.060	0.036	-0.081	-0.112	-0.108
	(0.087)	(0.088)	(0.091)	(0.092)	(0.092)
Size (more than 250)	0.991*	0.894*	0.613*	0.585*	0.550*
	(0.090)	(0.092)	(0.097)	(0.099)	(0.100)
Domestic Group	0.613*	0.619*	0.550*	0.565*	0.561*
	(0.083)	(0.084)	(0.086)	(0.087)	(0.087)
Foreign Group	0.386*	0.382*	0.376*	0.467*	0.445*
	(0.118)	(0.120)	(0.123)	(0.125)	(0.126)
Product and Process Innovations		0.739*	0.519*	0.490*	0.497*
		(0.068)	(0.071)	(0.072)	(0.073)
Deviation from R&D industry average		1.628*	1.142*	0.923**	0.878**
		(0.386)	(0.413)	(0.419)	(0.420)
Innovation Sources					
Intramural R&D			0.671*	0.601*	0.578*
			(0.076)	(0.077)	(0.078)
External R&D			1.005*	0.918*	0.910*
			(0.080)	(0.082)	(0.083)
Public Funds					
Local public funds				0.680*	0.575*
				(0.082)	(0.085)
National public funds				0.444*	0.342*
				(0.102)	(0.104)
European public funds					1.020*
					(0.135)
_cons	-2.420*	-2.690*	-2.872*	-2.992*	-2.983*
	(0.066)	(0.072)	(0.076)	(0.078)	(0.079)
N	6733	6733	6733	6733	6733

Source: author's elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%

Table 58: Average marginal effects of the logit model for cooperation with other firms and institutions

	(1)	(2)	(3)	(4)	(5)
	All partners	**All partners**	**All partners**	**All partners**	**All partners**
Industry variables					
High-tech	0.091*	0.060*	0.014	0.010	0.008
	(0.016)	(0.015)	(0.013)	(0.013)	(0.013)
KIS	0.073*	0.064*	0.072*	0.083*	0.085*
	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
Average industry investments in innovation activities	2.420*	2.353*	1.299*	0.828*	0.516***
	(0.304)	(0.303)	(0.305)	(0.306)	(0.311)
Firm variables					
Size (50-249)	0.008	0.004	-0.010	-0.013	-0.013
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Size (more than 250)	0.163*	0.141*	0.088*	0.083*	0.076*
	(0.016)	(0.016)	(0.015)	(0.015)	(0.015)
Domestic Group	0.087*	0.086*	0.072*	0.073*	0.071*
	(0.012)	(0.012)	(0.011)	(0.011)	(0.011)
Foreign Group	0.058*	0.056*	0.052*	0.064*	0.060*
	(0.019)	(0.019)	(0.018)	(0.018)	(0.018)
Product and Process Innovations		0.107*	0.070*	0.064*	0.064*
		(0.010)	(0.010)	(0.010)	(0.010)
Deviation from R&D industry average		0.222*	0.147*	0.116**	0.109**
		(0.052)	(0.053)	(0.053)	(0.052)
Innovation Sources					
Intramural R&D			0.092*	0.080*	0.076*
			(0.011)	(0.011)	(0.011)
External R&D			0.156*	0.138*	0.135*
			(0.014)	(0.014)	(0.014)
Public Funds					
Local public funds				0.095*	0.079*
				(0.013)	(0.013)
National public funds				0.061*	0.046*
				(0.015)	(0.015)
European public funds					0.157*
					(0.024)
N	6733	6733	6733	6733	6733

Source: author's elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

Table 59: Coefficients of the logit model for cooperation with group firms

	(1)	(2)	(3)	(4)	(5)
	Group firms	**Group firms**	**Group firms**	**Group firms**	**Group firms**

	b/se	b/se	b/se	b/se	b/se
Industry variables					
High-tech	0.750*	0.515*	0.294**	0.265***	0.254***
	(0.131)	(0.135)	(0.139)	(0.141)	(0.142)
KIS	0.664*	0.559*	0.645*	0.707*	0.728*
	(0.132)	(0.135)	(0.138)	(0.140)	(0.141)
Average industry investments in innovation activities	11.962*	11.094*	6.033***	3.188	0.667
	(2.972)	(3.221)	(3.377)	(3.493)	(3.538)
Firm variables					
Size (50-249)	0.081	0.058	-0.017	-0.052	-0.011
	(0.155)	(0.158)	(0.160)	(0.162)	(0.162)
Size (more than 250)	1.274*	1.140*	0.930*	0.889*	0.878*
	(0.137)	(0.142)	(0.146)	(0.148)	(0.149)
Domestic Group	-0.296**	-0.304**	-0.370*	-0.433*	-0.409*
	(0.118)	(0.121)	(0.123)	(0.124)	(0.126)
Foreign Group	.	.	.	.	.
	.	.	.	.	.
Product and Process Innovations		1.037*	0.863*	0.842*	0.872*
		(0.112)	(0.116)	(0.116)	(0.117)
Deviation from R&D industry average		2.361*	1.944*	1.850*	1.906*
		(0.596)	(0.615)	(0.623)	(0.629)
Innovation Sources					
Intramural R&D			0.417*	0.358*	0.298**
			(0.124)	(0.125)	(0.126)
External R&D			0.823*	0.733*	0.727*
			(0.114)	(0.117)	(0.118)
Public Funds					
Local public funds				0.389*	0.241***
				(0.131)	(0.136)
National public funds				0.417*	0.264***
				(0.135)	(0.141)
European public funds					0.961*
					(0.170)
Model					
_cons	-2.736*	-3.149*	-3.282*	-3.269*	-3.292*
	(0.162)	(0.174)	(0.179)	(0.180)	(0.182)
N	3661	3661	3661	3661	3661

Source: author's elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

Table 60: Average marginal effects of the logit model for cooperation with group firms

	(1)	(2)	(3)	(4)	(5)
	Group firms	**Group firms**	**Group firms**	**Group firms**	**Group firms**
	b/se	b/se	b/se	b/se	b/se

Industry variables					
High-tech	0.090*	0.057*	0.030**	0.027***	0.025***
	(0.018)	(0.016)	(0.015)	(0.015)	(0.015)
KIS	0.077*	0.061*	0.069*	0.075*	0.076*
	(0.017)	(0.016)	(0.016)	(0.016)	(0.016)
Average industry investments in innovation activities	1.249*	1.116*	0.589***	0.308	0.063
	(0.309)	(0.323)	(0.329)	(0.338)	(0.336)
Firm variables					
Size (50-249)	0.006	0.004	-0.001	-0.004	-0.001
	(0.011)	(0.012)	(0.012)	(0.012)	(0.012)
Size (more than 250)	0.146*	0.124*	0.098*	0.093*	0.089*
	(0.014)	(0.014)	(0.014)	(0.015)	(0.014)
Domestic Group	.	.	.	.	.
	.	.	.	.	.
Foreign Group	.	.	.	.	.
	.	.	.	.	.
Product and Process Innovations		0.106*	0.085*	0.082*	0.084*
		(0.011)	(0.011)	(0.011)	(0.011)
Deviation from R&D industry average		0.238*	0.190*	0.179*	0.181*
		(0.060)	(0.060)	(0.060)	(0.060)
Innovation Sources					
Intramural R&D			0.041*	0.035*	0.028**
			(0.012)	(0.012)	(0.012)
External R&D			0.091*	0.079*	0.077*
			(0.014)	(0.014)	(0.014)
Public Funds					
Local public funds				0.040*	0.024***
				(0.014)	(0.014)
National public funds				0.044*	0.027***
				(0.015)	(0.015)
European public funds					0.115*
					(0.025)
N	3661	3661	3661	3661	3661

Source: author's elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

Table 61: Coefficients of the logit model for cooperation with clients and suppliers

	(1)	(2)	(3)	(4)	(5)
	Clients and Suppliers	**Clients and Suppliers**	**Clients and Suppliers**	**Clients and Suppliers**	**Clients and Suppliers**
	b/se	b/se	b/se	b/se	b/se
Industry variables					
High-tech	0.869*	0.644*	0.354***	0.333***	0.325***

	(0.186)	(0.190)	(0.192)	(0.193)	(0.194)
KIS	0.201	0.111	0.218	0.258	0.263
	(0.215)	(0.216)	(0.218)	(0.219)	(0.220)
Average industry investments in innovation activities	14.954*	14.167*	6.663	4.612	2.776
	(3.924)	(4.138)	(4.334)	(4.486)	(4.546)
Firm variables					
Size (50-249)	0.233	0.201	0.063	0.041	0.072
	(0.215)	(0.217)	(0.219)	(0.220)	(0.220)
Size (more than 250)	1.062*	0.907*	0.569**	0.534**	0.515**
	(0.212)	(0.216)	(0.222)	(0.226)	(0.226)
Domestic Group	0.447**	0.431**	0.326	0.325	0.312
	(0.212)	(0.214)	(0.215)	(0.215)	(0.215)
Foreign Group	0.460***	0.445***	0.421	0.460***	0.404
	(0.267)	(0.269)	(0.270)	(0.271)	(0.273)
Product and Process Innovations		1.021*	0.744*	0.729*	0.733*
		(0.164)	(0.168)	(0.169)	(0.169)
Deviation from R&D industry average		1.521**	0.943	0.838	0.839
		(0.718)	(0.757)	(0.767)	(0.775)
Innovation Sources					
Intramural R&D			1.064*	1.031*	1.002*
			(0.192)	(0.193)	(0.194)
External R&D			0.627*	0.569*	0.554*
			(0.163)	(0.166)	(0.167)
Public Funds					
Local public funds				0.274	0.159
				(0.174)	(0.180)
National public funds				0.255	0.121
				(0.189)	(0.198)
European public funds					0.714*
					(0.220)
Model					
_cons	-4.599*	-5.007*	-5.304*	-5.335*	-5.307*
	(0.172)	(0.192)	(0.208)	(0.210)	(0.210)
N	6733	6733	6733	6733	6733

Source: author’s elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

Table 62: Average marginal effects of the logit model for cooperation with clients and suppliers

	(1)	(2)	(3)	(4)	(5)
	Clients and suppliers	**Clients and suppliers**	**Clients and suppliers**	**Clients and suppliers**	**Clients and suppliers**
Industry variables					
High-tech	0.030*	0.020*	0.010***	0.009	0.009
	(0.008)	(0.007)	(0.006)	(0.006)	(0.006)
KIS	0.006	0.003	0.006	0.007	0.007
	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)
Average industry investments in innovation activities	0.405*	0.380*	0.176	0.122	0.073
	(0.109)	(0.113)	(0.115)	(0.119)	(0.119)
Firm variables					
Size (50-249)	0.005	0.004	0.001	0.001	0.002
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Size (more than 250)	0.033*	0.027*	0.016**	0.015**	0.014**
	(0.007)	(0.007)	(0.006)	(0.006)	(0.006)
Domestic Group	0.012**	0.011**	0.009	0.009	0.008
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Foreign Group	0.014	0.014	0.013	0.014	0.012
	(0.010)	(0.009)	(0.009)	(0.009)	(0.009)
Product and Process Innovations		0.027*	0.019*	0.019*	0.019*
		(0.004)	(0.004)	(0.004)	(0.004)
Deviation from R&D industry average		0.041**	0.025	0.022	0.022
		(0.019)	(0.020)	(0.020)	(0.020)
Innovation sources					
Intramural R&D			0.026*	0.025*	0.025*
			(0.005)	(0.005)	(0.005)
External R&D			0.018*	0.016*	0.016*
			(0.005)	(0.005)	(0.005)
Public funds					
Local public funds				0.008	0.004
				(0.005)	(0.005)
National public funds				0.007	0.003
				(0.006)	(0.006)
European public funds					0.024*
					(0.009)
N	6733	6733	6733	6733	6733

Source: author's elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

Table 63: Coefficients of the logit model for cooperation with competitors

	(1)	(2)	(3)	(4)	(5)
	Competitors	**Competitors**	**Competitors**	**Competitors**	**Competitors**
	b/se	b/se	b/se	b/se	b/se
Industry variables					
High-tech	0.283***	0.136	-0.096	-0.147	-0.180
	(0.147)	(0.149)	(0.152)	(0.154)	(0.158)
KIS	0.507*	0.461*	0.517*	0.599*	0.630*
	(0.129)	(0.130)	(0.131)	(0.132)	(0.134)
Average industry investments in innovation activities	13.732*	13.141*	7.426*	3.629	0.164
	(2.625)	(2.730)	(2.870)	(3.007)	(3.099)
Firm variables					
Size (50-249)	0.032	0.018	-0.063	-0.103	-0.082
	(0.136)	(0.138)	(0.139)	(0.140)	(0.140)
Size (more than 250)	0.795*	0.707*	0.485*	0.444*	0.390*
	(0.137)	(0.141)	(0.145)	(0.148)	(0.149)
Domestic Group	0.423*	0.419*	0.355*	0.362*	0.352*
	(0.129)	(0.130)	(0.131)	(0.132)	(0.132)
Foreign Group	0.015	-0.001	-0.012	0.072	0.004
	(0.191)	(0.192)	(0.194)	(0.195)	(0.198)
Product and Process Innovations		0.616*	0.431*	0.396*	0.407*
		(0.104)	(0.108)	(0.108)	(0.109)
Deviation from R&D industry average		1.566*	1.178**	0.998***	1.001***
		(0.488)	(0.508)	(0.520)	(0.524)
Innovation Sources					
Intramural R&D			0.648*	0.573*	0.530*
			(0.117)	(0.118)	(0.120)
External R&D			0.528*	0.421*	0.403*
			(0.118)	(0.121)	(0.122)
Public Funds					
Local public funds				0.615*	0.446*
				(0.116)	(0.121)
National public funds				0.458*	0.259***
				(0.136)	(0.144)
European public funds					1.198*
					(0.155)
_cons	-3.394*	-3.619*	-3.762*	-3.863*	-3.836*
	(0.101)	(0.109)	(0.114)	(0.117)	(0.118)
N	6733	6733	6733	6733	6733

Source: author's elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

Table 64: Average marginal effects of the logit model for cooperation with competitors

	Competitors	Competitors	Competitors	Competitors	Competitors
	b/se	b/se	b/se	b/se	b/se
Industry variables					
High-tech	0.018***	0.008	-0.005	-0.008	-0.010
	(0.010)	(0.010)	(0.008)	(0.008)	(0.008)
KIS	0.034*	0.030*	0.034*	0.039*	0.041*
	(0.010)	(0.009)	(0.010)	(0.010)	(0.010)
Average industry investments in innovation activities	0.820*	0.777*	0.434*	0.209	0.009
	(0.158)	(0.162)	(0.168)	(0.173)	(0.175)
Firm variables					
Size (50-249)	0.002	0.001	-0.003	-0.005	-0.004
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Size (more than 250)	0.056*	0.048*	0.031*	0.028*	0.024**
	(0.011)	(0.010)	(0.010)	(0.010)	(0.010)
Domestic Group	0.025*	0.025*	0.021*	0.021*	0.020*
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Foreign Group	0.001	-0.000	-0.001	0.004	0.000
	(0.012)	(0.011)	(0.011)	(0.012)	(0.011)
Product and Process Innovations		0.038*	0.026*	0.023*	0.023*
		(0.007)	(0.007)	(0.006)	(0.006)
Deviation from R&D industry average		0.093*	0.069**	0.058***	0.057***
		(0.029)	(0.030)	(0.030)	(0.030)
Innovation Sources					
Intramural R&D			0.039*	0.034*	0.031*
			(0.007)	(0.007)	(0.007)
External R&D			0.035*	0.027*	0.025*
			(0.009)	(0.008)	(0.008)
Public funds					
Local public funds				0.041*	0.028*
				(0.009)	(0.008)
National public funds				0.030*	0.016***
				(0.010)	(0.009)
European public funds					0.101*
					(0.018)
N	6733	6733	6733	6733	6733

Source: author's elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

Table 65: Coefficients of the logit model for cooperation with Universities

	(1)	(2)	(3)	(4)	(5)
	Universities	**Universities**	**Universities**	**Universities**	**Universities**
	b/se	b/se	b/se	b/se	b/se
Industry variables					
High-tech	0.920*	0.733*	0.341*	0.290**	0.283**
	(0.115)	(0.118)	(0.124)	(0.129)	(0.132)
KIS	0.406*	0.327*	0.482*	0.622*	0.670*
	(0.121)	(0.123)	(0.129)	(0.132)	(0.134)
Average industry investments in innovation activities	25.859*	26.484*	17.133*	11.901*	8.535*
	(2.425)	(2.497)	(2.690)	(2.805)	(2.922)
Firm variables					
Size (50-249)	0.339*	0.319**	0.165	0.095	0.138
	(0.130)	(0.131)	(0.136)	(0.139)	(0.141)
Size (more than 250)	1.535*	1.435*	1.061*	1.021*	1.001*
	(0.125)	(0.129)	(0.136)	(0.141)	(0.142)
Domestic Group	0.734*	0.725*	0.608*	0.625*	0.602*
	(0.129)	(0.130)	(0.134)	(0.137)	(0.138)
Foreign Group	0.281***	0.260	0.226	0.358**	0.274
	(0.170)	(0.172)	(0.178)	(0.183)	(0.186)
Product and Process Innovations		0.793*	0.459*	0.417*	0.436*
		(0.095)	(0.100)	(0.103)	(0.104)
Deviation from R&D industry average		1.478*	0.603	0.202	0.118
		(0.500)	(0.559)	(0.581)	(0.594)
Innovation Sources					
Intramural R&D			1.085*	0.975*	0.925*
			(0.112)	(0.114)	(0.116)
External R&D			1.289*	1.160*	1.170*
			(0.099)	(0.102)	(0.104)
Public Funds					
Local public funds				0.986*	0.829*
				(0.108)	(0.112)
National public funds				0.707*	0.545*
				(0.118)	(0.124)
European public funds					1.353*
					(0.149)
Model					
_cons	-3.849*	-4.152*	-4.583*	-4.797*	-4.800*
	(0.112)	(0.121)	(0.135)	(0.141)	(0.142)
N	6733	6733	6733	6733	6733

Source: author's elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

Table 66: Average marginal effects for cooperation with Universities

	Universities	Universities	Universities	Universities	Universities
	b/se	b/se	b/se	b/se	b/se
Industry variables					
High-tech	0.083*	0.062*	0.024*	0.019**	0.018**
	(0.012)	(0.011)	(0.009)	(0.009)	(0.009)
KIS	0.032*	0.025**	0.035*	0.043*	0.045*
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Average industry investments in innovation activities	1.916*	1.924*	1.141*	0.756*	0.524*
	(0.176)	(0.178)	(0.177)	(0.177)	(0.179)
Firm variables					
Size (50-249)	0.019**	0.018**	0.009	0.005	0.007
	(0.007)	(0.007)	(0.008)	(0.008)	(0.008)
Size (more than 250)	0.138*	0.124*	0.080*	0.074*	0.069*
	(0.013)	(0.012)	(0.011)	(0.011)	(0.010)
Domestic Group	0.054*	0.052*	0.040*	0.040*	0.037*
	(0.009)	(0.009)	(0.009)	(0.009)	(0.008)
Foreign Group	0.022	0.020	0.016	0.024***	0.018
	(0.014)	(0.014)	(0.013)	(0.013)	(0.013)
Product and Process Innovations		0.060*	0.031*	0.027*	0.027*
		(0.007)	(0.007)	(0.007)	(0.007)
Deviation from R&D industry average		0.107*	0.040	0.013	0.007
		(0.036)	(0.037)	(0.037)	(0.036)
Innovation Sources					
Intramural R&D			0.074*	0.063*	0.058*
			(0.008)	(0.008)	(0.007)
External R&D			0.108*	0.091*	0.088*
			(0.010)	(0.010)	(0.009)
Public funds					
Local public funds				0.074*	0.059*
				(0.009)	(0.009)
National public funds				0.052*	0.038*
				(0.010)	(0.010)
European public funds					0.116*
					(0.017)
N	6733	6733	6733	6733	6733

Source: author's elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

Table 67: Coefficients of the logit model for cooperation with public research centres

	(1)	(2)	(3)	(4)	(5)
	Public research centres	**Public research centres**	**Public research centres**	**Public research centres**	**Public research centres**
	b/se	b/se	b/se	b/se	b/se
Industry variables					
High-tech	0.780*	0.589*	0.214	0.103	0.073
	(0.153)	(0.156)	(0.161)	(0.167)	(0.172)
KIS	0.713*	0.635*	0.762*	0.919*	0.970*
	(0.150)	(0.151)	(0.156)	(0.161)	(0.164)
Average industry investments in innovation activities	21.413*	21.469*	12.795*	6.456**	2.256
	(2.607)	(2.749)	(2.954)	(3.160)	(3.288)
Firm variables					
Size (50-249)	0.275***	0.267	0.146	0.022	0.087
	(0.165)	(0.168)	(0.171)	(0.176)	(0.177)
Size (more than 250)	1.208*	1.102*	0.731*	0.597*	0.549*
	(0.161)	(0.166)	(0.173)	(0.180)	(0.183)
Domestic Group	0.582*	0.572*	0.447*	0.444**	0.414**
	(0.165)	(0.166)	(0.169)	(0.173)	(0.174)
Foreign Group	0.400***	0.377***	0.349	0.493**	0.389***
	(0.212)	(0.214)	(0.218)	(0.224)	(0.230)
Product and Process Innovations		0.825*	0.522*	0.472*	0.492*
		(0.124)	(0.128)	(0.131)	(0.134)
Deviation from R&D industry average		2.057*	1.375**	1.037***	1.056***
		(0.532)	(0.582)	(0.609)	(0.615)
Innovation Sources					
Intramural R&D			0.903*	0.754*	0.666*
			(0.145)	(0.149)	(0.151)
External R&D			1.239*	1.067*	1.094*
			(0.126)	(0.130)	(0.133)
Public Funds					
Local public funds				0.909*	0.693*
				(0.132)	(0.139)
National public funds				1.033*	0.824*
				(0.138)	(0.146)
European public funds					1.431*
					(0.165)
_cons	-4.334*	-4.667*	-5.034*	-5.220*	-5.194*
	(0.141)	(0.154)	(0.169)	(0.175)	(0.177)
N	6733	6733	6733	6733	6733

Source: author’s elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

Table 68: Average marginal effects of the logit model for cooperation with public research centres

	(1)	(2)	(3)	(4)	(5)
	Public Research Centres	**Public Research Centres**	**Public Research Centres**	**Public Research Centres**	**Public Research Centres**
	b/se	b/se	b/se	b/se	b/se
Industry variables					
High-tech	0.043*	0.030*	0.009	0.004	0.003
	(0.010)	(0.009)	(0.007)	(0.007)	(0.007)
KIS	0.037*	0.032*	0.037*	0.044*	0.045*
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Average industry investments in innovation activities	0.967*	0.953*	0.541*	0.260**	0.087
	(0.120)	(0.124)	(0.125)	(0.127)	(0.126)
Firm variables					
Size (50-249)	0.009	0.009	0.005	0.001	0.003
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Size (more than 250)	0.063*	0.055*	0.033*	0.026*	0.022*
	(0.009)	(0.009)	(0.008)	(0.008)	(0.008)
Domestic Group	0.026*	0.025*	0.019*	0.018*	0.016**
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Foreign Group	0.020***	0.019	0.016	0.022***	0.016
	(0.012)	(0.012)	(0.011)	(0.011)	(0.011)
Product and Process innovations		0.037*	0.022*	0.019*	0.019*
		(0.006)	(0.005)	(0.005)	(0.005)
Deviation from R&D Industry average		0.091*	0.058**	0.042***	0.041***
		(0.024)	(0.025)	(0.024)	(0.024)
Innovation Sources					
Intramural R&D			0.037*	0.030*	0.025*
			(0.006)	(0.006)	(0.006)
External R&D			0.065*	0.051*	0.050*
			(0.008)	(0.007)	(0.007)
Public funds					
Local public funds				0.043*	0.030*
				(0.007)	(0.007)
National public funds				0.053*	0.039*
				(0.009)	(0.008)
European public funds					0.085*
					(0.014)
N	6733	6733	6733	6733	6733

Table 69: Coefficients of the logit model for cooperation with Italian Universities

	(1)	(2)	(3)	(4)	(5)	(6)
	Italian Universities	**Italian Universities**	**Italian Universities**	**Italian Universities**	**Italian Universities**	**Italian Universities**
	b/se	b/se	b/se	b/se	b/se	b/se
Industry variables						
High-tech	0.884*	0.702*	0.299**	0.240***	0.231***	0.293***
	(0.117)	(0.120)	(0.127)	(0.131)	(0.134)	(0.157)
KIS	0.429*	0.352*	0.507*	0.644*	0.685*	0.402**
	(0.122)	(0.124)	(0.130)	(0.133)	(0.135)	(0.158)
Average industry investments in innovation activities	25.534*	26.086*	16.640*	11.405*	8.276*	9.362*
	(2.425)	(2.498)	(2.705)	(2.820)	(2.924)	(3.535)
Firm variables						
Size (50-249)	0.272**	0.253***	0.097	0.021	0.060	0.035
	(0.132)	(0.134)	(0.139)	(0.142)	(0.143)	(0.166)
Size (more than 250)	1.524*	1.429*	1.053*	1.006*	0.985*	0.983*
	(0.127)	(0.130)	(0.137)	(0.142)	(0.143)	(0.166)
Domestic Group	0.717*	0.708*	0.588*	0.602*	0.580*	0.541*
	(0.130)	(0.131)	(0.135)	(0.138)	(0.139)	(0.160)
Foreign Group	0.177	0.154	0.109	0.233	0.148	0.009
	(0.174)	(0.176)	(0.182)	(0.187)	(0.191)	(0.222)
Product and Process Innovations		0.764*	0.425*	0.381*	0.397*	0.262**
		(0.096)	(0.102)	(0.104)	(0.105)	(0.122)
Deviation from R&D industry average		1.518*	0.652	0.268	0.195	-0.568
		(0.499)	(0.559)	(0.580)	(0.590)	(0.827)
Innovation Sources						
Intramural R&D			1.089*	0.980*	0.933*	0.809*
			(0.114)	(0.116)	(0.117)	(0.135)
External R&D			1.315*	1.185*	1.193*	1.016*
			(0.100)	(0.103)	(0.105)	(0.125)
Public Funds						
Local public funds				0.954*	0.809*	0.697*
				(0.109)	(0.113)	(0.133)
National public funds				0.732*	0.582*	0.335**
				(0.119)	(0.124)	(0.151)
European public funds					1.218*	0.553*
					(0.151)	(0.196)
Cooperation with others						
Cooperation with customers and suppliers						1.348*
						(0.212)
Cooperation with						1.543*

competitors						
						(0.156)
Cooperation with research centres						2.926*
						(0.175)
_cons	-3.840*	-4.130*	-4.568*	-4.770*	-4.762*	-5.010*
	(0.112)	(0.121)	(0.135)	(0.141)	(0.142)	(0.162)
N	6733	6733	6733	6733	6733	6733

Source: author's elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

Table 70: Average marginal effects for cooperation with Italian Universities

	(1)	(2)	(3)	(4)	(5)	(6)
	Italian Universities	**Italian Universities**	**Italian Universities**	**Italian Universities**	**Italian Universities**	**Italian Universities**
	b/se	b/se	b/se	b/se	b/se	b/se
Industry variables						
High-tech	0.077*	0.058*	0.021**	0.016***	0.015***	0.014***
	(0.012)	(0.011)	(0.009)	(0.009)	(0.009)	(0.008)
KIS	0.033*	0.027*	0.036*	0.044*	0.046*	0.019**
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.008)
Average industry investments in innovation activities	1.841*	1.847*	1.079*	0.707*	0.499*	0.417*
	(0.172)	(0.174)	(0.174)	(0.174)	(0.176)	(0.158)
Firm variables						
Size (50-249)	0.015**	0.014***	0.005	0.001	0.003	0.001
	(0.007)	(0.007)	(0.008)	(0.007)	(0.007)	(0.006)
Size (more than 250)	0.136*	0.122*	0.078*	0.072*	0.068*	0.050*
	(0.013)	(0.012)	(0.011)	(0.011)	(0.010)	(0.009)
Domestic Group	0.051*	0.050*	0.038*	0.037*	0.035*	0.024*
	(0.009)	(0.009)	(0.009)	(0.008)	(0.008)	(0.007)
Foreign Group	0.013	0.011	0.007	0.015	0.009	0.000
	(0.014)	(0.013)	(0.012)	(0.013)	(0.012)	(0.010)
Product and Process Innovations		0.056*	0.028*	0.024*	0.024*	0.012**
		(0.007)	(0.007)	(0.007)	(0.006)	(0.006)
Deviation from R&D industry average		0.107*	0.042	0.017	0.012	-0.025
		(0.035)	(0.036)	(0.036)	(0.036)	(0.037)
Innovation Sources						
Intramural R&D			0.072*	0.062*	0.058*	0.037*
			(0.008)	(0.007)	(0.007)	(0.006)
External R&D			0.108*	0.091*	0.089*	0.054*
			(0.010)	(0.009)	(0.009)	(0.008)
Public Funds						
Local public funds				0.070*	0.056*	0.035*
				(0.009)	(0.009)	(0.008)

National public funds				0.053*	0.040*	0.016**
				(0.010)	(0.010)	(0.008)
European public funds					0.100*	0.028**
					(0.016)	(0.012)
Cooperation with others						
Cooperation with customers and suppliers						0.087*
						(0.019)
Cooperation with competitors						0.104*
						(0.015)
Cooperation with research centres						0.298*
						(0.029)
N	6733	6733	6733	6733	6733	6733

Table 71: Coefficients of the logit model for cooperation with foreign Universities

	(1)	(2)	(3)	(4)	(5)	(6)
	Foreign Universities	**Foreign Universities**	**Foreign Universities**	**Foreign Universities**	**Foreign Universities**	**Foreign Universities**
	b/se	b/se	b/se	b/se	b/se	b/se
Industry variables						
High-tech	1.168*	0.950*	0.582**	0.479**	0.458***	0.610**
	(0.229)	(0.233)	(0.234)	(0.240)	(0.252)	(0.283)
KIS	0.321	0.211	0.376	0.516***	0.507***	0.333
	(0.276)	(0.277)	(0.281)	(0.288)	(0.303)	(0.329)
Average industry investments in innovation activities	32.406*	32.892*	24.115*	18.026*	12.988*	13.611*
	(3.538)	(3.700)	(3.878)	(4.127)	(4.431)	(4.952)
Firm variables						
Size (50-249)	0.331	0.310	0.199	0.034	0.242	0.183
	(0.297)	(0.301)	(0.304)	(0.309)	(0.314)	(0.343)
Size (more than 250)	1.565*	1.426*	1.027*	0.843*	0.820*	0.481
	(0.279)	(0.286)	(0.293)	(0.301)	(0.309)	(0.339)
Domestic Group	1.190*	1.163*	1.037*	1.048*	0.972*	0.940**
	(0.337)	(0.339)	(0.341)	(0.345)	(0.349)	(0.381)
Foreign Group	0.982**	0.947**	0.944**	1.128*	0.877**	0.990**
	(0.386)	(0.389)	(0.392)	(0.398)	(0.409)	(0.447)

Product and Process Innovations		0.950*	0.645*	0.578*	0.647*	0.339
		(0.207)	(0.211)	(0.213)	(0.224)	(0.245)
Deviation from R&D industry average		1.399***	0.616	0.238	0.550	-0.926
		(0.813)	(0.827)	(0.868)	(0.922)	(1.001)
Innovation Sources						
Intramural R&D			1.465*	1.291*	1.057*	0.743**
			(0.290)	(0.294)	(0.303)	(0.324)
External R&D			0.901*	0.701*	0.737*	0.445***
			(0.194)	(0.200)	(0.209)	(0.235)
Public Funds						
Local public funds				0.897*	0.473**	0.305
				(0.199)	(0.218)	(0.239)
National public funds				0.969*	0.480**	0.042
				(0.202)	(0.226)	(0.257)
European public funds					2.110*	1.575*
					(0.222)	(0.250)
Cooperation with others						
Cooperation with customers and suppliers						1.111*
						(0.277)
Cooperation with competitors						0.688*
						(0.247)
Cooperation with research centres						2.383*
						(0.249)
Model						
_cons	-6.299*	-6.672*	-7.348*	-7.481*	-7.441*	-7.493*
	(0.316)	(0.335)	(0.391)	(0.394)	(0.399)	(0.427)

Source: author’s elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

Table 72: Average marginal effects for cooperation with foreign Universities

	(1)	(2)	(3)	(4)	(5)	(6)
	Foreign Universities	**Foreign Universities**	**Foreign Universities**	**Foreign Universities**	**Foreign Universities**	**Foreign Universities**
Industry variables						
High-tech	0.027*	0.020*	0.011**	0.009***	0.007***	0.008**
	(0.007)	(0.006)	(0.005)	(0.005)	(0.004)	(0.004)
KIS	0.006	0.004	0.007	0.010	0.008	0.004
	(0.006)	(0.005)	(0.006)	(0.006)	(0.006)	(0.004)
Average industry investments in innovation activities	0.588*	0.588*	0.422*	0.303*	0.197*	0.170*
	(0.072)	(0.074)	(0.071)	(0.070)	(0.068)	(0.062)
Firm variables						
Size (50-249)	0.004	0.003	0.002	0.000	0.003	0.002
	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)
Size (more than 250)	0.031*	0.027*	0.018*	0.015*	0.012*	0.006
	(0.006)	(0.005)	(0.005)	(0.005)	(0.005)	(0.004)
Domestic Group	0.021*	0.020*	0.017*	0.017*	0.014*	0.011**
	(0.006)	(0.006)	(0.006)	(0.005)	(0.005)	(0.005)
Foreign Group	0.024***	0.022***	0.021***	0.025**	0.016***	0.015***
	(0.012)	(0.012)	(0.011)	(0.012)	(0.009)	(0.008)
Product and Process Innovations		0.016*	0.011*	0.009*	0.009*	0.004
		(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Deviation from R&D industry average		0.025***	0.011	0.004	0.008	-0.012
		(0.015)	(0.014)	(0.015)	(0.014)	(0.013)
Innovation Sources						
Intramural R&D			0.020*	0.018*	0.014*	0.009**
			(0.003)	(0.003)	(0.004)	(0.004)
External R&D			0.017*	0.012*	0.012*	0.006***
			(0.004)	(0.004)	(0.004)	(0.003)
Public Funds						
Local public funds				0.017*	0.008**	0.004
				(0.004)	(0.004)	(0.003)
National public funds				0.019*	0.008***	0.001
				(0.005)	(0.004)	(0.003)
European public funds					0.058*	0.028*
					(0.010)	(0.006)
Cooperation with others						
Cooperation with customers and suppliers						0.018*
						(0.006)

Cooperation with competitors						0.010**
						(0.004)
Cooperation with research centres						0.052*
						(0.009)
N	6733	6733	6733	6733	6733	6733

Source: author's elaboration. Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%

Appendix 2

The Questionnaire to the Institutions

1. Role as an actor of the innovation system and approach to ‘Industry 4.0’
2. Database of projects developed and main funding tools
3. Good practices
4. Strengths and weaknesses of Trento’s innovation system

The Questionnaire to the Enterprises

1. Main information:

1.1. Name of the company
1.2. VAT number
1.3. NACE Code
1.4. Total number of employees in 2015
1.5. Total revenues in 2015
1.6. Family-owned and managed

2. Background:

2.1. Brief history of the company, recent developments and evolution and main drivers of competitive advantage
2.2. Management structure and organization
2.3. Share of exports and main countries of exports
2.4. Share of employees with a bachelor or master degree

3. Usage of the ‘Industry 4.0’ key technologies:

3.1. Use of technologies able to automatically identify or store information concerning products or objects (e.g. RFID or QR Code). Main purpose of adoption:

- monitor access (e.g. badge)
- monitor or control industrial production (from the semi-manufactured to the final product)
- identify the final products in the post-production phase
- monitor or control the delivery process

3.2. Sharing Supply Chain Management (SCM) information electronically

3.3. Use of a sensor system for data processing (environmental or processing data)

3.4. Acquisition of cloud computing services

3.5. Use of advanced automation systems (robots or drones) for production or logistics

3.6. Use of Human Machine Interaction (HMI) devices (display touch, scanner 3D, wearables)

3.7. Use of 3D printing machines; main purpose:

- for prototypes of final products
- for final products
- for components of the final products

3.8. Main advantages related to the adoption of these technologies:

- Automatic data collection and sharing of information
- Traceability of products
- Data exchange with other objects
- Environmental monitoring
- Products with a higher quality and better features
- More efficient production processes
- Less defects
- Higher flexibility in the production process

3.9. Main obstacles related to the adoption of these technologies:

- Hacking risks and security breach
- The need to upgrade internal competences and knowledge to manage the new technologies
- High investments in infrastructures
- Limited maturity of these technologies
- Lack of specialized technological providers

3.10. Presence of an ICT specialist

3.11. Training for ICT specialists or for other employees

4. Approach to Research and Development (R&D) activities (if existent):

- Internal or external R&D
- Descriptions of the main phases developed from the concept, to the design, the prototyping, the manufacturing and commercialization
- Main critical areas of the research and development process

5. Cooperation in innovation activities during 2013-2015:

5.1 Main players involved in innovation activities:

- Competitors or companies operating in the same sector
- Suppliers
- Private clients
- Consultants, private laboratories, private research centres
- Consortiums
- Public Administration
- Universities and public research centres
- Professional Institutes

5.2 Importance of the public actor for innovation activities

5.3 Participation to public calls for innovation projects

5.4 Type of public fund received:

- Local funds
- National funds
- European Union funds

5.5 Total amount of public funds received

6. Main strengths and weaknesses related to Trento's innovation system

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